A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Plastic Waste Hierarchy-Technology Readiness Level and Circular Economy Practices of Hospitals in the Philippines

Christine May GAYLAN

June 2023

Vienna

Erasmus Mundus Masters Course in
Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfillment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

(3) For bibliographic and reference purposes this thesis should be referred to as:

Gaylan, CM. 2023. *Plastic Waste Hierarchy-Technology Readiness Level and Circular Economy Practices of Hospitals in the Philippines*. Master of Science thesis, Central European University, Vienna.

Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Christine May GAYLAN

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:
Christine May GAYLAN
for the degree of Master of Science and entitled: *Plastic Waste Hierarchy-Technology Readiness Level and Circular Economy Practices of Hospitals in the Philippines*
Month and Year of submission: June 2023

Plastic wastes in the hospital setting include polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA), which classified according to their resin identification. Plastic wastes may be medical or non- medical, and reusable or non-reusable. The current medical waste classification system does not account for the quantity of the plastic wastes generated in hospitals. There has been a surge of medical waste production brought about by the COVID-19 pandemic which has also increased plastic waste generation. While the reduction of plastic use has been identified in several government plans and policies as a priority, there is a lack of understanding and support in plastic waste minimization in hospitals in view of their nature as major waste generators. This study developed the Plastic Waste and Sustainability Assessment Tool and Waste Hierarchy- Technology Readiness Levels (WH-TRL) Framework for Philippine waste treatment and disposal technologies with the aim of assessing the waste management practices of hospitals in terms of their alignment to the circular economy principles. This study serves as a baseline data collection on the hospitals' waste management practices in line with sustainability and circular economy, specifically, on the consumption of plastics and succeeding plastic waste generation. The assessment tool may be adopted by the facility as a policy and planning tool and a guide for institutional strengths, weaknesses, opportunities, and threats (SWOT) analysis. Moreover, the assessment tool will supplement the existing waste management guidelines and may be utilized as an internal audit or evaluation tool. The study has found that pyrolysis and incineration are the technologies with the highest maturity and circularity potential. The knowledge of the composition and amount of plastic wastes generated enables their efficient collection, maximizing the recycling rate of core materials and potentially prolonging their use phase and their lifecycle. It is recommended to conduct further cost- benefit analyses on the adoption of pyrolysis and modernized incineration in the treatment of both medical and non- medical plastic wastes in order to recycle plastic resins and energy, and reduce the volume of wastes disposed in sanitary landfills. The establishment of public- private partnerships is also recommended for co-financing on infrastructure supporting renewable energy and rainwater harvesting. Capacity development for hospital staff and waste service providers or TSDs should also be developed. Furthermore, it is recommended that the government support the transition of hospitals into sustainability in terms of waste management, energy and water efficiency, and material sustainability to minimize their carbon footprint and adapt to and mitigate climate change.

Keywords: medical plastic waste, healthcare sustainability, healthcare circular economy, waste hierarchy, waste technology readiness level

Acknowledgements

To my professors in the MESPOM program, especially my adviser, Prof. Zoltan Illes,

To the Erasmus+: Erasmus Mundus Programme which granted me the scholarship,

To the management and staff of the Central European University,

To my mentors and technical advisers in environmental health,

To my key resource persons and their respective hospitals,

I am grateful for your guidance and support. The learnings from this study and the whole program will be forever invaluable to me.

To my beloved family and friends, thank you for the solidarity in advocating environmental health.

My MESPOM journey may have come to an end but never the struggle for a healthy environment. May science and technology always be for the people and the environment.

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1 Background of the Study

Medical wastes from hospitals are classified according to the standards of the World Health Organization (2018) which include infectious, pathological, sharps, chemical, pharmaceutical, cytotoxic, radioactive, and non-hazardous or general wastes (Department of Health 2020). General wastes constitute the majority of the wastes produced in hospitals in the Philippines, followed by pathological and pharmaceutical wastes, which are reported to be at 893,317 and 125,779 metric tons, respectively, from January 2019 to October 2021 (Department of Environment and Natural Resources 2021). There has been a three- to six- fold increase of medical waste generation due to the COVID-19 pandemic, as reported by the Department of Environment and Natural Resources (2021). However, the existing waste classification system does not account for plastic consumption and waste generation in the hospital setting.

In this study, medical plastic waste includes but not limited to medical and non-medical plastic and personal protective equipment. Specifically, the type of plastics considered in this study are based on the ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification, which includes polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA). Medical plastics are directly utilized in the provision of treatment and diagnosis, such as syringe, blood transfusion tubes, and urine bags. As such, most of these plastic wastes are considered infectious as they have come in contact with the patient or specimen. Non- medical wastes, on the other hand, are mostly general wastes which are not directly related to healthcare services, such as plastic bottles, packaging, plastic utensils, and sachets. Table 1 lists the classification of both medical and non-medical plastics and some examples. The Philippine Action Plan for Sustainable Consumption and Production (PAP4SCP) 2021 identifies as one of its priorities the practice of circular economy through the implementation of choice- editing strategy and extended producer responsibility (EPR) policy. The short- term goal is to significantly reduce the generation of single- use plastics while the medium- term objective is to develop products or their substitute with a longer utility and shorter residual material life- cycle. Moreover, the Philippine Green Public Procurement System (GPP) of 2019 mandates the shift to climate-smart health facilities which observe sustainable consumption and waste production and green economy. This implies that the technical specification of products and materials to be procured and used in the hospital are environmentally- friendly and that the principle of waste minimization is observed. While the need to shift to sustainable practices and materials through the reduction of plastic wastes is recognized, there is not much attention on the hospital setting.

Table 1. Classification of medical and non-medical plastics

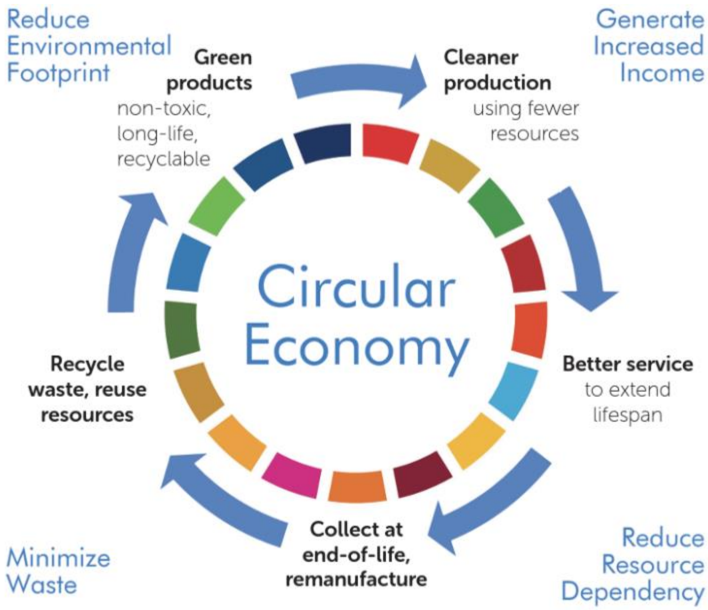
Types of Plastic	Examples in the Healthcare Setting
polyethylene terephthalate or polyester (PET/PETE)	water or drinks bottles, textile fabrics
high-density polyethylene (HDPE)	milk or yogurt drink bottles, waste bags, intravenous (IV) fluid containers, syringe barrels
polyvinyl chloride (PVC)	blood bags, IV bags, tubing, catheters, respiratory masks, disposable gloves
low-density polyethylene (LDPE)	plastic bags, plastic films, other flexible packaging
polypropylene (PP)	syringes, sterilisation “blue” wrap, irrigation bottles, basins, cups and disposable items e.g., surgical masks, gowns, caps, shoe covers, drapes
polystyrene and expanded polystyrene or styrofoam (PS)	plastic cutlery, yoghurt cups, fruit and vegetable trays, clear solid packaging, test tubes, fast food packaging, packing peanuts, insulation
polycarbonate (PC)	medical tubing, catheters, incubators, syringes, blood oxygenators, baby bottles
polyurethane (PUR)	Sponge
polyamide (PA)	Tea bags
nitrile rubbers	Disposable gloves
polylactide (PLA)	Coffee cup lids, yogurt pods

Source: Health Care Without Harm, 2021

The healthcare sector is accountable for ten percent of the total greenhouse gas emissions produced by the United States in 2015, with one third generated by hospitals alone (Health Care Climate Council 2020). In 2021, it is said that the health care sector generated 5% of the world's greenhouse gas emissions or a carbon footprint of around 514 coal powerplants (The Health Policy Partnership 2022). In 2008, the energy consumption of healthcare facilities in the United States is found to be at 10.3% of that of the private sector which is at 10,073 million metric tons (Bawaneh et al. 2019, 1-2). Meanwhile, water consumption in hospitals is estimated to be at 133 billion gallons or 144.8 thousand gallons per patient bed during the 2007 commercials buildings consumption survey in the United States (US Energy Information Administration 2012). Currently, there is no data on the greenhouse gas emissions of the 1,284 hospitals (as of 2022) in the Philippines (Department of Health 2023).

Circular economy is a concept of product life cycle extension, as it gives a sustainable model of production and consumption (European Parliament 2023). While the concept of circular economy is traditionally seen as consisting of reduce, reuse, recycle, and remanufacture (United Nations Conference on Trade and Development 2023), it can also be seen as comprised of waste minimization, reduction of resource dependency, reduction of environmental footprint, and generation of increased income (Figure 1) (United Nations Industrial Development Organization 2017). According to the United Nations Environment Programme (2022), the global transition to circular economy will decrease greenhouse gas emissions by 25%, reduce marine plastic pollution by 80%, and increase government savings by 70 billion USD by 2040. Circular economy will impart to the reduction of the hospital's carbon footprint and their overall contribution to climate change mitigation through sustainable materials management approach (United States Environmental Protection Agency 2022). Adopting circular economy in the hospital setting will entail the practice of sustainability practices holistically and in various areas such as operations; procurement; personnel training; waste management; information, education, and communication (IEC) materials; and infrastructure, equipment, and devices. Circular economy in the hospital setting focuses on reduction of waste generation and energy and water efficiency. Hence, the study has developed the Plastic Waste and Sustainability Assessment Tool as a guide for hospitals to preliminarily assess their practices and operations vis-à-vis the circular economy principles.

Figure 1. Circular economy model



Source: United Nations Industrial Development Organization 2017

The Waste Hierarchy is a guide to sustainable waste management which highlights the prevention of waste generation as a priority (European Commission 2017). The hierarchy has five levels with promoting reuse, recycling, and recovery following prevention in the level of priorities, respectively. Disposal is the least preferred method and at the bottom of the Waste Hierarchy pyramid as circular economy promotes maximization of products and materials. Wastage and pollution may be prevented through reuse, sharing, repairing, and recycling (Bourguignon 2016). Increasing level of circularity is observed as the level in the Waste Hierarchy goes higher (Department for Environment Food and Rural Affairs 2011). Meanwhile, the Technology Readiness Level (TRL) is a technique to measure the maturity of a technology in terms of its deployment to the end- users to serve its intended purpose. Every technology is assessed against a set of parameters corresponding to each level, with TRL ratings between 1 and 9, with the latter as the highest (National Aeronautics and Space Administration 2012). In this study, the Waste Hierarchy-Technology Readiness Levels (WH-TRL) Framework as described by Rybicka et. al. (2016) will be utilized to assess the existing waste management practices of hospitals in the Philippines to determine their position in the waste hierarchy and the waste technologies' level of readiness for implementation. Furthermore, the WH-TRL Framework evaluates the hospitals' waste management practices in terms of their alignment to the circular economy principles.

1.2 Significance of the Study

Effective management of medical wastes is vital to prevent the spread of diseases (Rushton 2003, 2-4). Improper burning of health care wastes causes the release of harmful chemicals such as particulate matter, dioxins, and furans (World Health Organization 2018). Particulate matter such as PM10 and PM2.5, are inhalable and can penetrate the lungs and bloodstream (Environmental Protection Agency 2018). The mixing of plastics with other medical wastes at any point of the waste hierarchy or stream poses significant threat to the environment. In a study using various plastics including black polycarbonate (BPC), polyethylene-terephthalate (PET), and polypropylene (PP), their steam gasification together with other waste and biomass produced higher volumes of CO and CO2 (Burra and Gupta, 2018). Carbon monoxide is a pollutant while carbon dioxide contributes to global warming. The incineration of plastic wastes releases an estimated 400Mt of CO2 annually (European Commission 2018). Plastics also has a long overall lifecycle, with the degradation period usually ranging from 20 to 500 years and relatively low percentage of recycling, with only 12% of 3 million tons recycled in 2021 in Australia (World Wide Fund for Nature 2021). The disposal of plastic wastes in landfills also pose a problem due to its lifespan, considering the very limited capacity of the 189 sanitary landfills in the Philippines which are also targeted to be increased by 300 more by 2022. It is projected that 12,000 million tons of plastic wastes will be generated by 2050 (Geyer et. al. 2017, 3-5). The seepage and leaching of degraded plastic waste particles pollute water systems (Wagner et. al. 2014, 3) and further pollute the soil and release toxic substances into agricultural landscapes, food, and drinking water (Alabi et. al., 3). Meanwhile, improper treatment and disposal of medical wastes result to the release of harmful microorganisms in the environment, including anti- microbial resistant microorganisms, compromising the health of the public. Some health risks related to the improper treatment and disposal of medical wastes include injuries from sharps and burning, chemical, thermal and radiation burns, exposure to antibiotics and cytotoxic drugs, and air pollution- related conditions such as respiratory and cardiovascular diseases (WHO 2018). In addition, improper management of medical wastes are potential hazards increasing the frequency and intensity of emergencies and disasters such as flooding and further contributing to increased public health risk.

Plastics have several negative environmental impacts throughout its life cycle. From the resource, i.e., oil and gas, extraction phase, fuel combustions produce direct emissions and methane leakage, and may also involve clearing of forests to establish pipelines (Health Care Without Harm 2019). Natural gas hydraulic fracturing produce methane emissions and other toxic chemicals (UNEP 2022). The manufacturing of plastics is an energy- intensive process which releases harmful emissions, and the use of plastics may release microplastics and microfibers which negatively impacts soil and marine life (Health Care Without Harm 2019). Medical and non-medical plastics are often not reused or recycled and most end up disposed in landfills or incinerated with other wastes. Due to overall slow decomposition of the various types of plastics, they take too much space in landfills and may produce microplastics and toxic chemicals which may leach out on soil and water bodies. Meanwhile, incineration of plastics is harmful as it has high CO2 emissions and produces toxic ashes and air pollutants such as dioxins and furans.

For years, the healthcare sector has been overlooked as a major contributor to greenhouse gas emissions. Currently, there is a lack of extensive studies on carbon footprint of hospitals globally, including energy and water consumption and efficiency. In the Philippines, hospitals do not perform waste audits to determine the volume and composition of their generated wastes. With the information on the type of wastes produced, especially plastics, they will be able to be segregated and recycled accordingly. The conduct of waste audits trigger awareness on waste minimization by providing insights in which areas resource use and waste generation can be reduced. Moreover, while there are national guidelines on the management of medical wastes, there are no assessment tools or practical guide on the reduction of the amount of plastic consumed and waste generated, particularly in hospitals, which are known to highly contribute to the production of plastic wastes.

This study contributes to the baseline data collection on the hospitals' institutional strengths, weaknesses, opportunities, and threats (SWOT) analysis in terms of their waste management and sustainability practices. The Plastic Waste and Sustainability Assessment Tool developed to the hospitals supplement the existing checklist and guidelines on waste management and may be used a policy and planning tool at various levels, e.g., institutional, local, regional, and national. The assessment tool may be adopted by the hospital to conduct internal audits and evaluate their own waste management practices and supply chain in terms of sustainability. Knowing their position in terms of the WH-TRL Framework will create awareness on their current condition versus the available waste management techniques and technologies. Hence, it may be a basis for the development of capacity building programs, in line with the recommendation in the Department of Health's Health Care Waste Management Manual Fourth Edition (2020) to establish the hospital's own Waste Management Committee and develop their set of guidelines or a handbook. This study will assist the hospital in evaluating their supply chain and inventory, determining the inflow and outflow of materials in their institution through procurement and waste outputs. As such, the tools may aid in financial forecasting and may be used a basis for additional funding requests for institutional enhancement such as for waste management and sustainability capacity building. Furthermore, this research will serve as a pilot study on the current waste management, sustainability, and circular economy practices in the Philippines in terms of plastic waste.

1.3 Scope and Limitation

The scope of the study will include medical plastic wastes such as medical and non-medical plastic and personal protective equipment. The type of plastics considered are as follows: the type of plastics considered in this study include polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA). The generalizability of the results of this study should be taken with caveat as the study sites are limited to five major public hospitals in the National Capital Region of the country. The respondents of this study are hospital from the Engineering Department of the hospitals, which are usually in-charge of waste management. As such, they might not have thorough knowledge on other areas of hospital operations such as procurement. The study also employed purposive sampling in which there are limited respondents, i.e., three per hospital, due to staff availability. The online nature of the questionnaire entails that for Part C – Waste Audit of the assessment tool, the responses are only based on estimates and there might be no actual measurements done or no readily available data on wastes generated. Furthermore, due to the confidentiality and non- disclosure agreement, the name of the hospitals and the respondents had been included.

1.4 Research Objectives and Hypotheses

The aim of this study was to assess the waste management practices of hospitals in the Philippines in terms of their alignment to the circular economy principles. Specifically, it aims to:

i. Develop a Plastic Waste and Sustainability Assessment Tool to generally evaluate the hospitals' waste management practices;
ii. Determine the position of the waste management techniques used in the hospitals in the Waste Hierarchy; and
iii. Determine the Technology Readiness Level rating of the waste treatment and disposal technologies utilized.

Below is a summary of the objective and outcome/output envisioned for this study:

Table 2. Research objectives and outcome/outputs

Objective	Outcome/Output
Assess the waste management practices of the hospitals	Plastic Waste and Sustainability Assessment Tool
Determine the position of the waste management techniques in the Waste Hierarchy	Waste Hierarchy-Technology Readiness Levels (WH-TRL) Chart or Cartesian Plane
Determine the TRL rating of waste treatment and disposal technologies	

It was hypothesized in this study that the waste management practices of the hospitals will be mostly at the lower levels, specifically in the Disposal level. The concept and practice of circular economy is relatively young in the Philippines, as evidenced by the newly formulated Philippine Action Plan for Sustainable Consumption and Production in 2020, which do not highlight the role of hospitals in plastic waste reduction. While waste prevention is promoted, there has been a steady increase in the generation of medical waste especially due to the COVID-19 pandemic, and the capacity of sanitary landfills are stretched with the aim of developing new facilities. The reuse and recycling of plastic wastes, specifically the medical plastic and personal protective equipment, may still not be realized due to limited research on its safety and the lack of onsite disinfection equipment even in major public hospitals. Recycling may have been practiced only in the non- medical plastics or general supplies such as those used in office keeping. It is also hypothesized that the TRL rating of the technologies used in the country are at levels 8 or 9 as it tends to adopt well- developed technologies which the other countries are already using. It may be said that the country does not invest on novel, upcoming technologies in waste management as funding for research and development is limited. If there will be waste management technologies in the lower TRL ratings, these may be unique techniques that are locally employed.

2. Literature Review

2.1 Health Care Waste and Classifications

Health care wastes are categorized by the World Health Organization (2018) into infectious, pathological, sharps, chemical, pharmaceutical, cytotoxic, radioactive, and non-hazardous or general wastes. Meanwhile, the Department of Health (2011) classifies health care wastes into infectious, pathological and anatomical, sharps, pharmaceutical, chemical, radioactive and non-hazardous or general. Table 3 below summarizes the descriptions and examples of health care waste classifications, according to the WHO (2018) and DOH (2011):

Table 3. Description and examples of health care waste categories

Type of Health Care Waste	Description	Examples
Infectious	Possibly contains pathogens and/or toxins in amounts which can infect or cause diseases in a host Includes all materials or equipment used on patients with infectious diseases	Microbial cultures from laboratories Wastes in contact with fluids from patients Swabs, bandages and similar materials used for patients
Pathological and Anatomical	Includes body tissues obtained from surgical procedures or biopsies Anatomical wastes as a subgroup include amputated body parts	Tissues, blood, placenta, organs, fetus, etc.
Cytotoxic	Wastes which contain genotoxic substances, i.e., mutagenic, teratogenic,	Cytotoxic drugs in cancer treatments and metabolites/by- products

	carcinogenic	
Sharps	Includes materials which can cut or puncture	Needles, syringes, blades, disposable scalpels, etc.
Chemical	Chemicals in solid, liquid, or gaseous phase which were used or produced in various health-related activities, i.e. disinfection, sterilization, including expired unused chemicals Categories include corrosive, reactive, toxic, and flammable chemical wastes Includes heavy metals and derivatives	Solvents and reagents used for surgical procedure, laboratories, disinfection, and film developing, etc. Mercury and cadmium from thermometers and sphygmomanometers
Pharmaceutical	Discarded, expired, or contaminated medicines, vaccines and pharmaceutical products	Empty drug containers including vials and connecting tubings
Radioactive	Includes all wastes exposed to radionuclides/ radioactive particles such as in diagnostics or therapy, i.e. exposed from cobalt (Co-60), technetium (Tc-99), iodine (I-131) and iridium (Ir-192)	Materials, fluids, and excretions exposed to radionuclides within 48 hours
General or Non-Hazardous	Wastes which do not raise public health hazards as they have not been in contact or	Office wastes, plastics, papers, bottles, pressurized containers, xray plates, etc.

	exposed to radioactive particles, harmful chemicals, and infectious agents	

The said categories of health care wastes may be generated from hospitals, health provider facilities, laboratories, research facilities, mortuaries and autopsy facilities, animal centers, blood banks, dermatology clinics, drug testing centers, rehabilitation centers, psychiatric homes and clinics, geriatric care centers, medical schools, and mobile ambulatory services (Department of Health 2011; WHO 2018).

2.2 Health Care Facilities (HCFs)

Health care facilities pertain to public, private, or non- governmental institutions which contributes to the improvement of the health of populations (Department of Health 2011). Health care facilities include hospitals, rural health units (RHUs), barangay health stations (BHS), and birthing facilities. Hospitals may be classified according to ownership, scope of services, and functional capacity (Department of Health 2012). Hospitals may be government-owned or private, based on ownership, and general or specialized based on the scope of services. In terms of functional capacity, hospitals may be general, specialized, and trauma-capable and/or trauma- receiving.

According to the DOH Administrative Order (AO) 2012- 0012 or the ‘Rules and Regulations Governing the New Classification of Hospitals and Other Health Facilities in the Philippines,’ other health care facilities which are not considered as hospitals are classified into category A/ primary care, category B/ custodial care, category C/ diagnostic or therapeutic, and category D/ specialized out- patient facilities (Department of Health 2012). Category A or primary care facilities include infirmaries, birthing homes, medical out- patient clinics, medical facilities for overseas Filipino workers (OFWs), and dental clinics. On the other hand, category B or custodial care facilities include custodial psychiatric care, substance or drug abuse treatment and rehabilitation center (DATRC), sanitarium/ leprosarium, and nursing homes. Meanwhile, category C or diagnostic/ therapeutic facilities include laboratories and radiologic centers.

Lastly, category D or specialized out- patient facilities include dialysis, ambulatory surgical, in-virto fertilization, oncology chemotherapeutic, and physical medicine and rehabilitation clinics, and stem cell and radiation oncology facilities. Table 4 shows the classification of hospitals and other health care facilities.

Table 4. Classification of hospitals and other health care facilities

Hospitals	Other Health Facilities
General	A. Primary Care Facility
Level 1	B. Custodial Care Facility
Level 2	C. Diagnostic/ Therapeutic Facility
Level 3 (Teaching/Training)	
Specialty	D. Specialized Out- Patient Facility

Source: Department of Health 2011

2.3 Health Care Waste Management (HCWM) Stream

The DOH Health Care Waste Management Manual (2011) as adopted from the WHO Guidance Manual for the Preparation of National Healthcare Waste Management Plans in Sub-Saharan Countries (2005), summarizes the stream of health care waste management, that is, the flow of health care waste from source or point of generation to final disposition, as seen in Figure 2.

It is said that the initial step or step 0 in handling health care wastes is the waste minimization which pertains to the planning stage, recycling of wastes, and the campaign to reduce volume of wastes produced. In HCFs, this is done through thorough inventory and supply chain management coupled with purchasing policies. The first step is the generation of health care wastes which occur in the medical units, followed by the segregation at source. This step is crucial so as to properly manage the wastes, prevent contamination and promote infection control. Hazardous or potentially infectious wastes should be separated immediately from sharps and general or non- hazardous wastes. The next step involves the collection and on- site transport of wastes inside the HCF into the onsite storage. For the collection of health care wastes, it is imperative that the personnel have a protective equipment such as gloves and masks and sealed containers and labelled, easy-to-wash trolleys should be used. On the other hand, storage rooms should be lockable, clean, and accessible only to authorized personnel. The ideal storage of health care wastes inside the HCF is around 24 to 48 hours. The HCF may opt to have an on- site or off- site treatment/ disposal, with the latter requiring a safe and certified off- site transport. The said transport mechanism should have an appropriate vehicle and consignment note. The final site destination of the vehicle and the treatment/ disposal site should be known to the HCF. The off- site transport, treatment and disposal are carried out by third party treatment, storage and disposal (TSD) facilities. These TSDs are accredited by the DENR prior to operation, as prescribed by the Joint DOH- DENR Administrative Order (JAO) 02 series of 2005, known as the 'Policies and Guidelines on Effective and Proper Handling, Collection, Transport, Treatment, Storage and Disposal of Health Care Wastes.'

Figure 2. Health care waste management stream

step	location	healthcare waste stream	key points
0		*waste minimization*	*purchasing policy; stock management; recycling of certain types of waste…*
1	in medical unit	**generation**	
2		**segregation at source**	*one of the most important steps to reduce risks and amount of hazardous waste*
3	in health facility	**collection + on-site transport**	*protective equipment; sealed containers; specific easy to wash trolleys*
4		**on-site storage**	*lockable easy to clean storage room; limited storage time of 24-48 hours*
5		**on-site treatment / disposal**	*adequate storage room; limited time of max 48 hours*
6	outside of health facility	**off-site transport**	*appropriate vehicle and consignement note; HCF is informed about final destination*
7		**off-site treatment / disposal**	*appropriate vehicle and consignement note to ensure…*

Source: Department of Health 2011

2.4 Basic Treatment Processes of Health Care Wastes

The treatment of health care wastes involves the minimization of biological and chemical hazards through sterilization and/or disinfection (DOH 2011). Sterilization is the reduction of the survival probability of resistant microogranisms to $6\log_{10}$ while disinfection is the minimization of specific microbial groups into low, intermediate or high levels based on the

Spaulding system (DOH 2011). For the disinfection of health care wastes, the following disinfection levels are used (DOH 2011):

Table 5. Levels of disinfection

Level of Disinfection	Description
I	Inactivation of vegetative bacteria, fungi and lipophilic viruses at $6\log_{10}$ reduction or greater
II	Inactivation of vegetative, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria at $6\log_{10}$ or higher
III	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria at a 6log10 reduction or greater; and inactivation of *B. stearothermophilus spores* and *B. subtilis spores* at $4\log_{10}$ reduction or greater
IV	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, *Mycobacterium* sp. and *B. stearothermophilus* spores at a $6\log_{10}$ reduction or greater

Source: World Health Organization 2018

The treatment of health care wastes, with disinfection at the minimum level, may be comprised of one or a combination of the five basic processes which include thermal, chemical, biological, irradiation, and mechanical processes, as described in the 'Safe Management of Wastes from Health-care Activities' Manual of the World Health Organization in 2014. Thermal treatment processes involve the use of heat or thermal energy to breakdown or inactivate pathogens present in waste. These processes may be further classified into low- heat and high- heat techniques. Low- heat thermal processes use heat at temperatures between the range of 100ºC to 180ºC which can destroy microorganisms at moist or dry-heat settings. Unlike high- heat techniques, low- heat processes do not cause pyrolysis or combustion of wastes. Low- heat treatment processes include microwave, autoclave, and frictional heat treatment while high- heat processes include pyrolysis and incineration.

Chemical treatment processes include the use of disinfectants such as sodium hypochlorite, dissolved chlorine dioxide, peracetic acid, lime solution, ozone gas and dry inorganic chemicals (WHO 2014). Manual soaking of wastes such as sharps and infectious wastes is considered as unreliable and is discouraged due to concerns on workers' safety and health. For anatomical and pathological wastes, chemical treatment processes involve the use of heated alkali in heated stainless- steel tanks to digest the tissues. Meanwhile, biological treatment processes are the degradation of organic matter present in health care wastes. These include the (a) use of enzymes to hasten decomposition of waste and disintegration of microorganisms, the (b) practice of composting and vermiculture, and (c) burial. Irradiation treatment processes, on the other hand, utilize radioactive particles for treatment of health care wastes. Ozone treatment is an example which causes the direct oxidation of cells causing the leakage of cell contents (US Environmental Protection Agency 1999). Lastly, mechanical process includes the physical reduction of size through shredders and mixers (WHO 2014).

2.5 Techniques and Technologies for the Treatment of Health Care Wastes in the Philippines

The common techniques used for the treatment of health care wastes include thermal, chemical, irradiation, biological, encapsulation, and inertization methods while specific technologies include pyrolysis, autoclave, and microwave (DOH 2011) (Table 6). Encapsulation and inertization may also be considered as disposal techniques. The list of available health care waste treatment technologies in the Philippines per category is found in the database of the Health Care Without Harm (2019) as well as the details of the supplier, capacity, and areas of global availability

Table 6. Techniques and technologies for treatment of health care wastes

Treatment Technology/ Methods	Description	Applicability	Remarks
Pyrolysis	Thermal decomposition of HCW in the absence of supplied molecular oxygen in the destruction chamber in which the said HCW is converted into gaseous, liquid, or solid form. Pyrolysis can handle the full range of HCW. Waste residues may be in form of greasy aggregates or slugs, recoverable metals, or carbon black. These residues are disposed of in a landfill.	All types of waste except mercury waste.	Costly. Not yet available in the country.
Autoclave	Uses steam sterilization to render waste harmless and is an efficient wet thermal disinfection process. This technique has been used for many years in hospitals for the sterilization of reusable medical equipment. Autoclaves come in a wide range of sizes. A typical autoclave designed for medical waste treats about 100 kg per cycle (a cycle being about 1 hour) to several hundred kilograms per cycle for larger hospitals. Autoclaves used in centralized treatment facilities	All types of waste except anatomical/ pathological, expired pharmaceutical drugs, cytotoxic, chemical, radioactive waste and mercury wastes. Autoclaves used for HCW should have built- in shredder.	Relatively low investment and operating costs. Available in different models and capacity to suit the needs of big and small HCFs. Has no significant environmental adverse impact.

	can handle as much as 3,000 kg in one cycle. The microbial inactivation efficacy of autoclaves shall be checked periodically. For autoclaves that do not shred waste during steam disinfection, color-changing indicator strips may be inserted inside the yellow bag in the middle of each load and that the strip shall be checked to ensure that steam penetration has occurred. In addition, a microbiological test (using for example commercially available validation kits containing *Bacillus stearothermophilus* spore strips, vials or packs) shall be conducted periodically or as the need arises.		
Microwave	This technology typically incorporates some type of size reduction device. Shredding of wastes is done before disinfection. In this process, waste is exposed to microwaves that raises the temperature to 100°C (237.6°F) for at least 30 minutes. Microorganisms are destroyed by moist heat which irreversibly coagulates and denatures enzymes and structural proteins.	The process is inappropriate for the treatment of anatomical waste and animal carcasses and will not efficiently treat chemical or pharmaceutical waste.	The system has a relatively high investment and operating costs. Not recommended for individual HCF.
Chemical	Chemical disinfection is also being used for	Chemical disinfection is most	Application of this method

disinfection	treatment of HCW. Chemicals like sodium hypochlorite, hydrogen peroxide, peroxyacetic acid and heated alkali are added to HCW to kill or inactivate pathogens present. It is recommended that sodium hypochlorite (bleach) with a concentration of 5% be used for chemical disinfection. If possible, HCW shall be shredded to increase the extent of contact between HCW and the disinfectant by increasing the surface area and eliminating the enclosed space. Some precautionary measures should be taken into consideration before using chemical disinfection: -Shredding and/or milling of waste is usually necessary before disinfection; the shredder is often the weak point in the treatment chain, being subject to frequent mechanical failure or breakdown. -Powerful disinfectants are required, which are themselves also hazardous and should be used only by well trained and adequately protected personnel. -Disinfection efficiency depends on operational	suitable in treating blood, urine, stools and sewage. This method is used in disinfecting highly infectious wastes at source as defined in this manual.	shall only be done when there is no available treatment facility in the area to prevent environmental problems associated in the indiscriminate use of chemicals as required by RA 8749 or the Clean Air Act and RA 9275 or the Clean Water Act.

	conditions. -Only the surface of intact solid waste will be disinfected.		
Biological processes	The process uses an enzyme mixture to decontaminate HCW. The resulting by-product is put through an extruder to remove water for wastewater disposal. The technology is suited for large applications and is also being developed for possible use in the agricultural sector. However, the technology requires regulation of temperature, pH, enzyme level, and other variables. Composting and vermin-culture as biological processes for food waste, yard trimmings and other organic waste are also recommended	Biodegradable wastes such as food waste, etc.	Design application is mainly for regional HCW treatment center.
Encapsulation	Encapsulation involves the filling of containers with waste, adding and immobilizing material, and sealing the containers. The process uses either cubic boxes made of high-density polyethylene or metallic drums, that are three-quarters filled with sharps or chemical or pharmaceutical residues. The containers or boxes are then filled up with a medium such as plastic foam, bituminous sand and	The process is particularly appropriated for the disposal of sharps and chemical (solid form) or pharmaceutical residues.	The main advantage of the process is that it is very effective in reducing the risk of scavengers gaining access to the HCW.

	cement mortar. After the medium has dried, the containers are sealed and disposed of in landfill.		
Inertization	Especially suitable for pharmaceutical waste is the process of inertization that involves the mixing of the waste with cement and other substances before disposal. For the inertization of pharmaceutical waste, the packaging shall be removed, the pharmaceuticals ground, and a mixture of water, lime and cement added. The homogenous mass produced can be transported to a suitable storage site. Alternatively, the homogeneous mixture can be transported in liquid state to a landfill and poured into municipal waste. The process is relatively inexpensive and can be performed using relatively unsophisticated equipment. The following is the typical proportion for the mixture: 65% pharmaceutical waste, 15% lime, 15% cement and 5% water.	The process is particularly appropriate for the disposal of sharps and chemical (solid form) or pharmaceutical residues.	This is to minimize the risk of toxic substances contained in the waste from migrating into the surface water or ground water.

2.6 Globally Available Technologies for the Treatment of Health Care Wastes

The World Health Organization (2005) in its 'Management of Solid Health-care Waste at Primary Health-Care Centers' provided the type of health care wastes in which the globally available treatment and disposal technologies are suited (Table 7). Meanwhile, the advantages and disadvantages of global health care waste treatment technologies in Table 8 were described by WHO (2019) in its 'Overview of Technologies for the Treatment of Infectious and Sharp Waste from Health Care Facilities.'

Table 7. Global treatment and disposal technologies and type of wastes treated

Treatment/ Disposal Technology	Type of Health Care Waste				
	Infectious (Non- plastic)	Anatomical	Sharps	Pharmaceutical	Chemical
Burial	Yes[1]	Yes[1]	Yes[1]	Yes[2]	Yes[2]
Sharp pit	No	No	Yes[1]	Yes[2]	No
Placenta pit	No	Yes[1]	No	No	No
Encapsulation	No	No	Yes	Yes	Yes[2]
Inertization	No	No	No	Yes	No
Low- temp burning (<800°C)	Yes	Yes	No	No	No
Med- temp burning (800-1000°C)	Yes	Yes	Yes	No	No
High- temp burning (>1000°C)	Yes	Yes	Yes	Yes[2]	Yes[2]
Steam autoclave	Yes	No	Yes	No	No
Microwave	Yes	No	Yes	No	No
Chemical disinfection	Yes	No	Yes	No	No
Discharge to sewer	No	No	No	Yes[3]	Yes[3]

[1]Disinfection prior treatment
[2]In small quantities only
[3]Only non-hazardous wastes

Table 8. Advantages and disadvantages of globally available health care waste treatment technologies

Technology	Advantages	Disadvantages
Vacuum autoclave	• Low environmental impacts • No hazardous residues • Complies with Stockholm Convention • Some treated wastes can be recycled	• Reliable solid waste collection required • Reliable water and electricity connection needed • Water needs to be of certain quality to protect the equipment • Temperature resistant waste bin or bags are needed • Residue recognizable, can cause injuries (e.g. sharps)
Autoclave with integrated shredding	• Low environmental impacts • No hazardous residues • Reduction of volume • Residue is unrecognizable • Complies with Stockholm Convention	• Reliable water and electricity connection needed • Water needs to be of certain quality to protect the equipment • Higher costs and maintenance (internal moving parts) • Requires a skilled operator
Batch wise microwave	• Low environmental impacts • No hazardous residues • Complies with Stockholm Convention	• Reliable solid waste collection required • Reliable electricity connection needed • Waste needs a minimum humidity or water needs to be added • Special waste bins are needed
Continuous microwave	• Low environmental impacts • Residue is non-hazardous	• Reliable electricity connection needed

	• Residue is unrecognizable • Reduction of waste volume • Complies with Stockholm Convention	• Higher costs and maintenance (internal moving parts) • Waste needs a minimum humidity or water needs to be added
Frictional heat treatment	• Low environmental impacts • Residue is non-hazardous • Reduction of waste volume • Residue is unrecognizable • Complies with Stockholm Convention	• Reliable electricity connection needed • Higher maintenance (internal moving parts)
Sodium hypochlorite treatment	• Low environmental impact • No hazardous residues • Reduction of waste volume • Residue is unrecognizable • Complies with Stockholm Convention	• Real time monitoring of chemical concentration is difficult • Strict occupational safety measures are necessary • Higher costs and maintenance (internal moving parts)
Automated pressure pulsing autoclave	• Low environmental impacts • No hazardous residues • Complies with Stockholm Convention	• Reliable electricity connection needed • Efficiency of waste decontamination is closely related to the type of waste treated (small lumen and porous material may not be decontaminated)
Dual chamber incinerator	• Reduction of waste volume • Residue is unrecognizable	• High environmental and health impact (air emissions and risk of burns) • Bottom and fly ash is potentially hazardous • Not in accordance with the Stockholm Convention

Single chamber incinerator	• Residue is unrecognizable • Reduction of waste volume	• Very high negative environmental and health impact (high air emissions) • Pathogens can survive the process • Bottom and fly ash is potentially hazardous • Not in accordance with the Stockholm Convention
Open burning	• No specific infrastructure or energy/water resources needed • Residue is mainly unrecognizable • Reduction of waste volume	• Very high negative environmental and health impact (very high air emissions) • Ash and emissions may contain viable pathogens • Remaining ash is potentially hazardous • Not in accordance with Stockholm Convention

Ozone treatment and incineration including flue gas treatment technologies were also identified but the advantages and disadvantages were not given.

2.7 Solid Health Care Waste Treatment Technologies used and Technology Adoption Strategies in the ASEAN+4

The health care waste treatment technologies used in the ASEAN+4 are the same as that of identified by the Philippine Department of Health and the World Health Organization. The HCW treatment technologies used, the adoption strategies through HCFs and/or TSDs, and the income levels using the World Bank classification of each country in the ASEAN+4 were compared in Table 9.

In Brunei Darussalam, burial of health care wastes is massively practiced according to its

Ministry of Development- Department of Environment, Parks and Recreation (2018). Uncontrolled incineration is also practiced in its two centralized health care facilities which also service the country's other HCFs (Ministry of Development 2018). Cambodia, on the other hand, treats and disposes its health care wastes through open burning, chemical disinfection, dry warm and wet treatments, microwave, burial in landfill and dumpsite, inertization, encapsulation, autoclave with shredder, and basic incinerator with no emission control system, as reported by Mr. Serey. Deputy Director of the EIA Department of the Ministry of Environment, in the Regional Workshop on Development of National and Strategy for Radioactive Waste Management held in 2014 at the IAEA, Vienna, Austria. Open burning is commonly practiced in its provinces while the TSDs are mostly centralized in its capital, Phnom Penh (Serey 2014, 2 ; WHO WPRO 2017). Incineration is mostly used centrally offsite in 10 waste treatment, storage, and disposal facilities (TSDs) and onsite in 180 health care facilities in Indonesia (WHO SEARO 2017; Irianti et al. 2015, 3). However, it was reported that the operation of incinerators in the HCFs are inefficient as wastes are piled up onsite (WHO SEARO 2017). Meanwhile, WHO WPRO (2015) reports the use of incinerators in Lao PDR but there was no data on offsite or onsite treatment practices.

The use of autoclave and incinerator for the treatment of healthcare wastes was reported in Malaysia (Razali and Ishak 2010, 2; Ambali et al. 2013, 3). Onsite and offsite treatment is practiced in three national TSDs (WHO WPRO 2015). In Myanmar, open burning, burial, and incinerator are used in TSDs and HCFs (World Bank 2014; WHO WPRO, 2015; Win et al. 2019, 4). On the other hand, Singapore practices the use of incinerators with flue gas treatment through five central TSDs (National Environment Agency 2020). The National Environment Agency (2020) reports that their incineration process has online monitoring of toxic gases and fugitive emission control. They also have succeeding wastewater treatment and flyash treatment to conform with leachate and toxic substances standards. Meanwhile, Thailand utilizes incinerators, autoclaves, and thermal inactivation (Panyaping and Okwumabua 2006, 3; Danchaivijitrmd et al. 2005, 2) in TSDs and four HCFs. WHO SEARO (2017) reports that only thermal inactivation is practiced in the HCFs and that the used double chamber incinerators in TSDs do not meet air quality standards while the flyash byproducts are disposed in landfills. Lastly for the ASEAN, Viet Nam uses autoclave, incinerator, microwave and chemical disinfection in both TSDs and HCFs (Nguyen 2018, 3; WHO WPRO 2015, 2; World Bank 2011). On the other hand, China was reported to treat healthcare wastes in centralized TSDs using incinerator, chemical disinfection, biological processes, pressure steam autoclave, electromagnetic wave sterilization and gasification (Gao et al. 2018, 2; Yong et al. 2008, 2; Li et al. 2006, 3). Meanwhile, Japan utilizes incinerators and melting facilities in TSDs and a few HCFs (WHO WPRO 2015). Centralized TSDs in Mongolia use low- temperature incinerators, autoclaves, microwaves, shredders and high-pressure steam autoclaves (WHO WPRO 2015). On the other hand, TSDs and HCFs in the Republic of Korea use burial, autoclave, microwave, and incinerator with scrubbers (Seo 2014, 3; United Nations Conference on Sustainable Development 2009; Jang 2005).

A study conducted by Voudrias (2016) reports that steam disinfection is the most appropriate treatment for infectious health care wastes. On the other hand, the technology recommendations of Hasan and Rahman (2018) and Jiang et al. (2012) based from their assessments conducted in Bangladesh and China, respectively, for the treatment of most health care wastes is incineration. However, Jiang et al. (2012) emphasized the need to optimize the process considering air pollution consequences.

Table 9. Health Care Waste Treatment Technologies, Adoption Strategies and Income Level Classification of ASEAN+4 Countries

Region	Country	Income Level Classification	HCW Treatment Technologies Commonly Used	HCW Treatment Technology Adoption Strategy
ASEAN	Brunei Darussalam	High	Uncontrolled incineration Burying	Centralized, in- house in 2 HCFs
	Cambodia	Lower middle	Burning Chemical disinfection Dry warm and wet treatment Microwave Burial in landfill and dumpsite Inertization and encapsulation Basic incinerator (no emission control system) Autoclave with shredder	Centralized TSDs
	Indonesia	Lower middle	Incinerator	In 10 TSDs and 180 HCFs
	Lao, People's Democratic Republic	Lower middle	Incinerator	No data obtained
	Malaysia	Upper middle	Autoclave Incinerator	Centralized, 3 TSDs
	Myanmar	Lower middle	Burning Burial Incinerator	TSDs and HCFs
	Philippines	Lower middle	Autoclave Microwave Chemical disinfection Biological processes Burial Encapsulation Inertization	TSDs, few HCFs
	Singapore	High	Incinerator with flue gas treatment	Centralized in 5 TSDs

	Thailand	Upper middle	Incinerator Autoclave Thermal inactivation	TSDs, 4 HCFs
	Viet Nam	Lower middle	Autoclave Incinerator Microwave Chemical disinfection	TSDs, HCFs
Non-ASEAN	China	Upper middle	Incinerator Chemical disinfection Biological processes Pressure steam autoclave Electromagnetic wave Sterilization Gasification	Centralized TSDs
	Japan	High	Incinerator Melting facilities	TSDs, few HCFs
	Mongolia	Lower middle	Low- temperature incinerators Autoclave Microwave Shredders High- pressure steam autoclaves	Centralized TSDs
	Republic of Korea	High	Incinerator Burial Autoclave Microwave	TSDs, HCFs

2.8 Recommended Criteria for Health Care Waste Treatment Technology Selection

The selection criteria for treatment technology used for health care wastes listed in the DOH Health Care Waste Management Manual 3rd edition (2011) include (a) treatment efficiency, (b) occupational health and safety and environmental considerations, (c) volume and mass reduction, (d) types and quantity of waste for treatment and disposal/ capacity of the system, (e) infrastructure and space requirements, (f) locally available treatment options for final disposal, (g) training requirements for operation of the method, (h) cost of operation and maintenance, (i) location/surroundings of the treatment site and disposal facility, (j) regulatory requirements, and (k) social and political acceptability. However, there is no in-depth discussion on the said criteria.

Similarly, the World Health Organization (2014) considers the (a) type and characteristic of waste, (b) capabilites and requirements of the technology, (c) environmental soundness and operational safety, (d) costs, and (e) compliance to national and international standards as primary criteria for the selection of health care waste treatment technology. Specific factors for evaluation include (a) types and volume of waste, (b) volume capacity of technology, (c) treatment efficiency, (d) volume and mass reduction, (e) occupational health and safety of operation, (f) environmental soundness, (g) facility space and infrastructure required, (h) availability of treatment for final disposal in local setting, (i) training requirements for technology operation, (j) operation and maintenance costs, (k) locational/ environmental requirements of treatment facility, (l) regulatory requirements, (m) sociopolitical acceptability, (n) treatment by- product transport and disposal costs, and (o) cost of technology shift/ withdrawal.

2.9 Emerging Issues in Health Care Waste Treatment Technologies

Technological advancements in the field of waste treatment require not only a catch- up in the knowledge and practice of healthcare facilities and waste TSD facilities but also in the governance aspect. Modernization in waste treatment is driven by the increasing volume of wastes, decrease of space available for landfills due to the growing population and sea level rise, and the increasing complexity of medical practices. Consequently, issues in the waste treatment technologies arise. According to the World Health Organization (2014), the technological issues and corresponding recommendations are as follows:

Table 10. Technological issues and recommendations in HCW treatment

Issue	Recommendation
Lack of information on advanced waste treatment technologies	Promotion of information dissemination and increased capacity for technology evaluation
Several products are non- recyclable	Shift to new designs and materials capable of reuse and recycling
Increasing use of disposable products	
Incineration is not applicable to some products such as PVC and mercury thermometers	Permanent phase-out of such products in medical practice
Technological solutions for marginalized and remote communities	Enhance segregation for proper waste treatment
	Development of waste treatment standards appropriate for various microbial inactivation and/or disinfection levels

2.10 Plastic Waste Classification and Recycling

Plastics found in the healthcare setting include different categories based on their resin polymers per the ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification, which include polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA).

Polyethylene terephthalate is a type of a thermoplastic polymer resin of polyester (Ji 2013, 406) with various industrial applications such as for fibers and films of packaging (Alagirusamy and Das 2011, 29) which constitutes 16% of the European plastic consumption (Nistico 2020, 1). Polyethylene terephthalate, commonly referred to interchangeably as polyester and the most dominant packaging for beverages in the form of bottles (Nistico 2020, 1), is manufactured through the polymerization of pure monoethylene glycol (MEG) and purified terephthalic acid (PTA) or dimethyl terephthalate (DMT) (Ji 2013, 406). In the hospital setting, PETE or PET usually exist in the form of water or drinks bottles and textile fabrics (Health Care Without Harm 2021).The natural decomposition of PET/PETE is a lengthy process, and they are recommended to be segregated from other wastes at disposal and recycled through chemical processes such as hydrolysis, methanolysis, glycolysis and aminolysis (Sinha et al. 2008, 8; Awaja and Pavel 2005, 1453). In most developed countries, the private sector also has established recycling centers for PET bottles as part of their extended producer responsibility (EPR).

High-density polyethylene (HDPE) in the hospital setting exists both as medical and non-medical of nature. Medical HDPEs are often infectious after use and include waste bags, intravenous (IV) fluid containers, and syringe barrels. Meanwhile, non-medical HDPEs may consist of milk or yogurt drink bottles. HDPEs are commonly accepted in curbside recycling drop off centers (Felous 2020). Polyvinyl chloride (PVC) is a thermoplastic synthetic resin of vinyl chloride (Takeoka 2014, 2) while low-density polyethylene (LDPE) is a thermoplastic produced from highly pressurized ethylene (Brittanica 2023) and free radical polymerization (Pham 2021, 2352). Polypropylene (PP) is a thermoplastic made through the polymerization of propylene gas (Koerner and Koerner 2018, 314) with several industrial applications such as for packaging, labelling, and household items due to its flexibility and affordability (Rani et al. 2023, 283). Similarly, polystyrene and expanded polystyrene or styrofoam (PS) have numerous industrial uses such as for packaging, cutleries, fillers, and insulation. However, PS, produced from styrene monomers which is a hydrocarbon from petroleum (Koerner et al. 2007, 36) is usually single- use and disposable (Merrington 2011, 177). Polycarbonate (PC) is a thermoplastic resin of chains of carbonate radicals and phenol (Freeman et al. 2018, 207) which is characterized by mechanical strength. Polyurethane (PUR) is produced from exothermic reaction between polyisocyanates and polyols (Park and Seo 2011, 431) while polyamide is characterized by a polymer chain of amide groups (Silva et al. 2010, 77). Nitrile rubber or nitrile-butadiene rubber (NBR) is an oil- resistant rubber made of acrylonitrile and butadiene (Brittanica 2023) while polylactide (PLA) is a derivative of lactic acid which is biodegradable at appropriate industrial composting conditions (Pang et al. 2010, 1125).

Recycling and recovery of plastics usually involve four types which are primary, secondary, tertiary, and quaternary (Hopewell et al. 2009, 2119). Both primary and secondary plastic recycling involves mechanical reprocessing into products while the main difference is that with the primary type, the end- product is of equivalent property while the secondary produces lower properties. Primary recycling is known as closed- loop recycling while secondary is termed downgrading (Hopewell et al. 2009, 2119). Tertiary recycling is chemical or feedstock recovery which usually involves depolymerization to the plastics' chemical components. Composting of biodegradable plastics fall under the tertiary category. Quaternary recycling, on the other hand, is energy recovery which may involve valorization or waste-to-energy (Hopewell et al. 2009, 2120). The recovery rate and common applications for re-use of the plastic recyclates, which are the by-products of recycling, are as follows (Merrington 2017, 168):

Table 11. Recovery rate and recyclate application of plastics

Plastic Type	Recovery Rate %	Recyclate Applications
polyethylene terephthalate or polyester (PET/PETE)	19.5	Fiber (clothing, carpet), film (balloons, packaging, thermal sheets, adhesive backing), bottles (pop, water), cosmetics packaging and food containers.
high-density polyethylene (HDPE)	10.3	Nonfood containers (laundry detergent, shampoo, conditioner, and motor oil bottles) plastic lumber, pipe, buckets, crates, flowerpots, film, recycling bins and floor tiles
polyvinyl chloride (PVC)	<1	Packaging, loose-leaf binders, decking, paneling, gutters, mud flaps, film, floor tiles and mats, traffic cones, electrical equipment, garden hoses and mobile home skirting
low-density polyethylene (LDPE)	5.3	Shipping envelopes, garbage can liners, floor tile, plastic lumber, food wrapping film, shopping bags, compost bins, dry cleaning bags and trashcans.
polypropylene (PP)	<1	Automobile battery cases, signal lights, brooms, oil funnels, brushes, ice scrapers, condiment bottles, margarine containers, yogurt containers, bicycle racks and rakes

polystyrene and expanded polystyrene or styrofoam (PS)	<1	Thermometers, light switch plates, thermal insulation, egg cartons, vents, rulers, license plate frames, foam packing, take-out food containers and disposable cutlery
polycarbonate (PC)	<1	Refillable plastic bottles, baby bottles, metal food can liners, consumer electronics, lenses
polyurethane (PUR)		Nylons - clothing, carpets, gears) Mixed plastics and blends -electronics housing, plastic lumber
polyamide (PA)		
nitrile rubbers		
polylactide (PLA)		Food and beverage containers

Source: Merrington 2017

Thermoplastics, including PET, HDPE, LDPE and PP all have high potential to be mechanically recycled (Merrington 2017, 172). Meanwhile, thermosetting polymers such as unsaturated polyester and epoxy resin cannot be mechanically recycled, except to be potentially re-used as filler materials once they have been size-reduced or pulverized to fine particles or powders (Merrington 2017, 173). Thermoset plastics are permanently cross-linked during manufacturing and cannot be re-melted and re-formed. The recycling of cross-linked rubbers from car tyres back to rubber crumb for re-manufacture into other products does occur and this is expected to grow owing to the EU Directive on Landfill of Waste (1999/31/EC), which bans the landfill of tyres and tyre waste (Merrington 2017, 173).
A major challenge for producing recycled resins from plastic wastes is that most different plastic types are not compatible with each other because of inherent immiscibility at the molecular level, and differences in processing requirements at a macro-scale (Merrington 2017, 172). For example, a small amount of PVC contaminant present in a PET recycle stream will degrade the recycled PET resin owing to evolution of hydrochloric acid gas from the PVC at a higher temperature required to melt and reprocess PET. Conversely, PET in a PVC recycle stream will form solid lumps of undispersed crystalline PET, which significantly reduces the value of the recycled material.

The common disposal routes of plastics include (a) landfilling, (b) incineration, (c) downgauging, (d) packaging re-use, and (e) recycling (Hopewell et al. 2009, 2121). The first step towards recovery upon disposal is collection which involves the use of collection bins or centers where people can bring and dispose off plastic wastes. Sorting, which may be done manually or automatically is the separation of plastic wastes from other waste types. Automatic sorting is usually employed by large material recovery facilities (MRFs) (Hopewell et al. 2009, 2121). Size reduction and cleaning is the breaking down of plastics into smaller pieces, usually the sturdy types, and consequent removal of unwanted residues such as food, pulp fibers, and adhesives. Further separation processes to separate by plastic resin type based on the ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification, may involve (a) sink/float separation in water to separate polyolefins (PP, HDPE, L/LLDPE) from PVC, PET and PS; (b) froth flotation to separate PVC contaminants from PET; (c) flake sorting for PETs; and (d) laser- sorting for differentiation per polymer type (Hopewell et al. 2009, 2121).

2.11 Technology Readiness, Adoption, and Leapfrogging

Technology adoption is the end- users' first and repeat purchase of an innovation (Shane 2008, 105-106) after its deployment and diffusion in the market. The rate at which technology is adopted in the market or its rate of performance improvement is known as the technology trajectory (Schilling 2013, 255-257). According to Shane (2008), factors affecting the adoption of a technology include the characteristics of the innovation, firm, environment and the adopter. The innovation characteristics affecting its rate of adoption include its relative advantage, relative cost price, perceived usefulness, ease of use, and network externality (Shane 2008, 105-106). Relative advantage is described as the benefits of adopting the new technology as compared to the purchase and shifting costs (Mohr et al. 2010, 6), in relation to the technology's greater functional than alternatives (Shane 2008, 105-106). The technology's usefulness and ease of use are said to be the dominant factors in technology adoption based on the technology acceptance model (TAM). Meanwhile, network externality is the increasing utility of an innovation as the number of adopters increases. Firm characteristics, on the other hand, include its size, marketing efforts, and reputation. In addition, the characteristics of the environment affecting technology adoption include infrastructure, market conditions, and availability and demand for associated products. Environmental infrastructure refers to the technological and economic enablers that support the adoption of the technology (Shane 2008, 105-106). Similarly, associated products include accessories and complementary products that further enhance the use of the technology of focus. Furthermore, adopter characteristics include economic class, risk disposition, economic value need, geodemographics, and word-of-mouth marketing behavior.

Adopters are further categorized into their purchasing behavior and timeline (Mohr et al. 2010; Schilling 2013). Technology enthusiasts or innovators are the first purchasers of new technologies for leisure purposes and out of curiosity. Early adopters or visionaries are key to the penetration of the market as they are interested in the applications and benefits of a technology while not relying on established references. Early majority or pragmatists adopt technologies slightly before than the average members of the society. They may not be opinion leaders but they can somehow influence others. The late majority or conservatives purchase technology only when there are established standards or references while needing lots of support from the company. Lastly, the laggards or skeptics are not much of a potential customer as they do not purchase technology if they are not integrated into another.

According to Mohr et al. (2010), factors such as relative advantage, compatibility, complexity, trialability, ability to communicate product benefits, and observability affect the purchasing decision of customers. Compatibility is the ease of adopting and using the technology with conformity to existing norms and standards while complexity is the difficulty of using the new technology. Trialability is the extent of trying a technology based on limited duration or feature. Meanwhile, the ability to communicate product benefits is the ease and clarity of conveying the use and benefits of a new technology to target end- users. Moreover, observability is seeing the technology's benefits experienced by the end- users.

Technology leapfrogging is a technological catch- up method for latecomers through quick and immediate adoption of a technology (Posadas 2009). It is a means of overtaking competitors or leaders through radical and disruptive innovations. Technology leapfrogging is one of the most cost- efficient and effective ways for developing countries to attain technological catch- up (Sauter and Watson 2008, 7). Some advantages of the latercomer's adoption of a diffused new technology include (1) avoiding its adoption at an early phase where there could still be major improvements and (2) access to cheaper technologies at their late phase of diffusion. Through leapfrogging, latecomers could avoid huge investments on older technologies as later stages may direct resources to more affordable and more advanced technologies. As such, Gallagher (2006) describes technological leapfrogging as the capability of developing countries geared towards industrialization to veer away from resource intensive development through the leapfrog to the most advanced technologies than following the path to advancement of highly- developed countries. Similarly, Steinmueller (2001) describes leapfrogging as bypassing some processes of capabilities and investment accumulation to bridge the gap in productivity and output for highly- industrialized and developing countries.

Risks in technology leapfrogging include the right selection of technologies from the pool of alternatives and the creation of initial market after the said selection (Sauter and Watson 2008, 7). In order to carry out technology leapfrogging, prerequisites include access to equipment and know-how, downstream integration of capabilities, access to complementary capabilities, and development of absorptive capacity.

3. Methodology

3.1 Data Collection

3.1.1 Study Site and Sample Size

The study site includes five tertiary (Level III) hospitals in the National Capital Region, Philippines which had been designated as COVID-19 referral hospitals. For each hospital, three respondents from the Engineering Department who are in- charge of health care waste management had been requested to serve as respondents to answer the Plastic Waste and Sustainability Assessment Tool. In most hospitals in the Philippines, the waste management functions lie within the Engineering Department with whom of which are commonly Sanitary Engineers or Inspectors who are of legal age, i.e., 18 to 65 years old. Purposive sampling had been utilized to select the hospitals while the respondents had been designated by their respective hospitals. The total of fifteen (15) respondents in this study from all of the five hospitals had been asked to answer the online assessment tool once and had been briefed of their right to confidentiality and right to withdrawal at any point of the study. For the purpose of confidentiality, the name of the respondents and of the hospitals had not been disclosed in this study. The timeline of activities is in Appendix A.

3.1.2 Plastic Waste and Sustainability Assessment Tool

The Plastic Waste and Sustainability Assessment Tool, deployed online through Google Forms (https://forms.gle/QXkvTDg1f5sZz7Wp8), is a three- part questionnaire which evaluated the existing capacities of hospitals in terms of their practices on plastic waste management and sustainability in line with the circular economy principles. The assessment tool had been designed to collect demographic information of the respondents while keeping their confidentiality. The questionnaire is comprised of three parts – (a) Personnel and Operations, (b) Infrastructure, Equipment, and Devices, and (c) Waste Audit. The first part, Personnel and Operations, reviewed if the hospital have in-house Waste Management Committee and Sustainability Committee, and if they have clear roles and responsibilities and if they receive regular trainings on the said subjects. It also assessed if green procurement is practiced in hospital and if the staff are able to recognize ecolabels based on ISO 14023. It also checked the availability of information, education and communication (IEC) materials for staff and patients on waste management, and water and energy efficiency and conservation. The second part of the assessment tool focused on Infrastructure, Equipment, and Devices, which reviewed which waste treatment and disposal technologies the hospitals have in-house and off-site through the services of their partner waste treatment, storage, and disposal (TSD) facilities. The waste TSD facilities are third- party waste service providers accredited by the Philippine Department of Environment and Natural Resources with the primary aim of processing wastes starting from collection until final disposal, both for municipal wastes and from public and private establishments such as hospitals. This section also evaluates the energy efficiency of the available technologies in the hospital in terms of lighting, ventilation, heating, and power source. Similarly, the water efficiency has been assessed in terms of drinking- water supply, handwashing facilities, presence of rainwater collection system, and safe plumbing connection system to a sewage treatment. Lastly, the assessment tool has a section on preliminary Waste Audit, which evaluates generally if the hospital has existing practices on the characterization of the quantity and composition of their generated wastes. The assessment tool reviews if the hospital analyses if their plastic wastes are reusable or non-reusable, and whether which types of plastics based on the ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification and the corresponding monthly volume are generated in each of the service area, i.e., emergency room, operating and delivery rooms, out- patient services, and wards. The overall feedback of the respondents on the questionnaire had also been solicited in Part D. Below is a copy of the online assessment tool.

Figure 3. Plastic Waste and Sustainability Assessment Tool

Plastic Waste and Sustainability Assessment Tool

In line with my thesis for the degree Erasmus Mundus Masters of Science in Environmental Science, Policy and Management entitled 'Plastic Waste Hierarchy- Technology Readiness Level and Circular Economy Practices of Hospitals in the Philippines', may I please request you to answer the below questionnaire.

Please be advised that all collected information will be strictly confidential and be used only for the purpose of the said event. Data collection, processing, and use will be subject to the Data Privacy Act of 2012. The name and hospital affiliation of the respondent will be confidential and not be disclosed and published in any part of the study.

For inquiries or concerns, you may contact Christine Gaylan at cmdrgatcg@gmail.com or +436706082225 (Whatsapp or Viber).

Thank you for your participation.

Respondent Information

Full Name *

Your answer

Email address *

Your answer

Contact Number (Whatsapp or Viber)

Your answer

Age *

- ◯ 18-35
- ◯ 36-50
- ◯ 51-65

Gender *

- Male
- Female
- Non-binary
- Prefer not to say

Number of years working in the hospital industry *

- 0-5
- 6-10
- 11-20
- 21 above

Name of Hospital Affiliation

Your answer

A. Personnel and Operations

1. Does the hospital have a Waste Management Committee? *

- Yes
- No
- Don't know

2. Does the hospital have a written guidelines or roles and responsibilities of the Waste Management Committee? *

- Yes
- No
- Don't know

3. Does the hospital conduct or receive training on waste management regularly? *

- Yes
- No
- Don't know

4. How often does the hospital staff receive training on waste management? *

- Just once
- Monthly
- Quarterly
- Annually
- Never
- Don't know

5. Does the hospital have a Sustainability Committee? *

- Yes
- No
- Don't know

6. Does the hospital have a written guidelines or roles and responsibilities of the Sustainability Committee? *

- Yes
- No
- Don't know

7. How often does the hospital staff receive training on sustainability? *

- Just once
- Monthly
- Quarterly
- Annually
- Never
- Don't know

8. Does the hospital have an existing policy or guideline on Green Procurement? *

- ◯ Yes
- ◯ No
- ◯ Don't know

9. Does the hospital practice the purchase of environmentally- friendly products, i.e., eco-labelled following ISO 14023? *

- ◯ Yes
- ◯ No
- ◯ Don't know

10. How often does the hospital staff receive training on green procurement? *

- ◯ Just once
- ◯ Monthly
- ◯ Quarterly
- ◯ Annually
- ◯ Never
- ◯ Don't know

11. Are the staff able to identify eco labels? *

- ◯ Yes
- ◯ No
- ◯ Don't know

12. Does the hospital have information, education and communication (IEC) materials for staff? *

	Yes	No	Don't know
Waste management	◯	◯	◯
Water efficiency and conservation	◯	◯	◯
Energy efficiency and conservation	◯	◯	◯

13. Does the hospital have information, education and communication (IEC) materials for patients and visitors? *

	Yes	No	Don't know
Waste management	◯	◯	◯
Water efficiency and conservation	◯	◯	◯
Energy efficiency and conservation	◯	◯	◯

B. Infrastructure, Equipment, and Devices

1. Does the hospital have onsite waste treatment technologies? *

◯ Yes

◯ No

◯ Don't know

2. Which technologies does the hospital have for waste treatment? Select all that apply. *

☐ Autoclave

☐ Microwave

☐ Chemical disinfection

☐ Encapsulation

☐ Inertization

☐ Biological processes, e.g., use of enzymes

☐ Burial

☐ Don't know

3. Does the hospital have a provider for offsite waste treatment, storage, and disposal? *

◯ Yes

◯ No

◯ Don't know

4. Which technologies are used by the waste TSD providers for waste treatment and disposal? *

- [ ] Pyrolysis
- [ ] Burial in Sanitary Landfill
- [ ] Open burning
- [ ] Incineration
- [ ] Autoclave
- [ ] Autoclave with shredder
- [ ] Frictional heat treatment
- [ ] Don't know

5. Does the hospital have energy- saving lighting, e.g., LED lights, use of natural daylight? *

- ○ Yes
- ○ No
- ○ Don't know

6. Does the hospital facility/equipment for harvest and storage of alternative energy sources, e.g., solar panel? *

- ○ Yes
- ○ No
- ○ Don't know

7. Which of the following technologies does the hospital have or rent as alternative energy sources? Select all that apply. *

- [ ] Solar panel
- [ ] Wind mill
- [ ] Hydroelectric
- [ ] Don't know

8. In your opinion, does the hospital maximise the use of natural lighting (daylight), e.g., windows to decrease need for light bulbs? *

- ○ Yes
- ○ No
- ○ Don't know

9. Can you say that the hospital have energy- efficient ventilation and cooling? *

- ○ Yes
- ○ No
- ○ Don't know

10. Which of the following technologies do the hospital have for ventilation and cooling? Select all that apply *

- ☐ Natural ventilation such as windows, high- ceiling halls
- ☐ Air-conditioning unit
- ☐ Electric fans
- ☐ Exhaust fans
- ☐ Roof insulation
- ☐ Don't know

11. Does the hospital have a power generator in case of power outages? *

- ○ Yes
- ○ No
- ○ Don't know

12. Does the hospital have infrastructure and facilities for safe drinking- water supply in all service areas? *

- ○ Yes
- ○ No
- ○ Don't know

13. Does the hospital have basic hand washing facilities in all service areas? *

- ○ Yes
- ○ No
- ○ Don't know

14. Does the hospital have rainwater collection system? *

- Yes
- No
- Don't know

15. Does the hospital have a plumbing connection system to a sewage treatment? *

- Yes
- No
- Don't know

C. Waste Audit

1. Does the hospital conduct a waste audit, i.e., analyze the quantity and composition of wastes generated in the hospital? *

- Yes
- No
- Don't know

2. How often does the hospital conduct waste audit? *

- Just once
- Monthly
- Quarterly
- Annually
- Bi-annually
- Never
- Don't know

3. Does the hospital categorise plastic wastes into reusable and non-reusable, e.g., plastic bottles are reusable while syringes are non-reusable and must be disposed of due to their infectious nature? *

- Yes
- No
- Don't know

4. Which of the following plastic wastes do the below hospital service areas generate, in general? Select all that may apply. *

a. PET/PETE (Polyethylene terephthalate, polyester): Water/drinks bottles, textile fabrics

b. HDPE (High-density polyethylene): Milk/yoghurt drink bottles, waste bags, IV fluid containers, syringe barrels

c. PVC (Polyvinyl chloride): Blood bags, IV bags, tubing, catheters, respiratory masks, disposable gloves.

d. LDPE (Low-density polyethylene): Plastic bags, plastic films, other flexible packaging

e. PP (Polypropylene): Syringes, sterilisation "blue" wrap, irrigation bottles, basins, cups and disposable items e.g., surgical masks, gowns, caps, shoe covers, drapes

f. PS (Polystyrene & Expanded polystyrene or Styrofoam): Plastic cutlery, yoghurt cups, fruit & vegetable trays, clear solid packaging, test tubes; Fast food packaging, packing "peanuts", insulation

g. PC (polycarbonate): Medical tubing, catheters, incubators, syringes, blood oxygenators, baby bottles

h. PUR (Polyurethane): sponges

i. PA (polyamide): tea bags

j. Nitrile rubbers: disposable gloves

k. PLA (polylactide): Coffee cup lids, yoghurt pots

	Emergency Room	Operating & Delivery Rooms	Out patient services	Wards	Others, please specify
PET/PETE	☐	☐	☐	☐	☐
HDPE	☐	☐	☐	☐	☐
PVC	☐	☐	☐	☐	☐
LDPE	☐	☐	☐	☐	☐
PP	☐	☐	☐	☐	☐
PS	☐	☐	☐	☐	☐
PC	☐	☐	☐	☐	☐
PUR	☐	☐	☐	☐	☐
PA	☐	☐	☐	☐	☐
Nitrile rubbers	☐	☐	☐	☐	☐
PLA	☐	☐	☐	☐	☐
Don't know - they are just all referred to as plastics	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐

5. Please provide an estimate of the plastic waste types generated in the **emergency rooms monthly.** *

	Less than 25kg	25-50 kg	51-75 kg	75-100kg	Above 100kg	Don't know
PET/PETE	☐	☐	☐	☐	☐	☐
HDPE	☐	☐	☐	☐	☐	☐
PVC	☐	☐	☐	☐	☐	☐
LDPE	☐	☐	☐	☐	☐	☐
PP	☐	☐	☐	☐	☐	☐
PS	☐	☐	☐	☐	☐	☐
PC	☐	☐	☐	☐	☐	☐
PUR	☐	☐	☐	☐	☐	☐
PA	☐	☐	☐	☐	☐	☐
Nitrile rubbers	☐	☐	☐	☐	☐	☐
PLA	☐	☐	☐	☐	☐	☐
Don't know - they are just all referred to as plastics	☐	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐	☐

6. Please provide an estimate of the plastic waste types generated in the **operating & delivery rooms monthly.** *

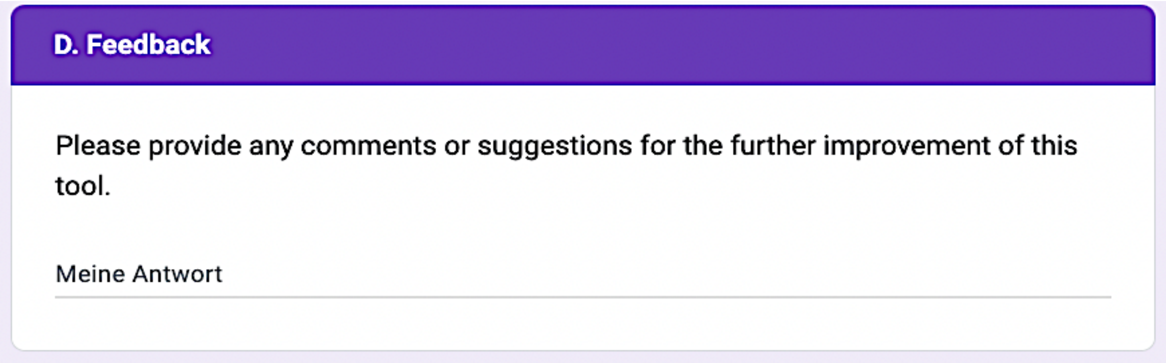
	Less than 25kg	25-50 kg	51-75 kg	75-100kg	Above 100kg	Don't know
PET/PETE	☐	☐	☐	☐	☐	☐
HDPE	☐	☐	☐	☐	☐	☐
PVC	☐	☐	☐	☐	☐	☐
LDPE	☐	☐	☐	☐	☐	☐
PP	☐	☐	☐	☐	☐	☐
PS	☐	☐	☐	☐	☐	☐
PC	☐	☐	☐	☐	☐	☐
PUR	☐	☐	☐	☐	☐	☐
PA	☐	☐	☐	☐	☐	☐
Nitrile rubbers	☐	☐	☐	☐	☐	☐
PLA	☐	☐	☐	☐	☐	☐
Don't know - they are just all referred to as plastics	☐	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐	☐

7. Please provide an estimate of the plastic waste types generated in the **out patient services monthly.** *

	Less than 25kg	25-50 kg	51-75 kg	75-100kg	Above 100kg	Don't know
PET/PETE	☐	☐	☐	☐	☐	☐
HDPE	☐	☐	☐	☐	☐	☐
PVC	☐	☐	☐	☐	☐	☐
LDPE	☐	☐	☐	☐	☐	☐
PP	☐	☐	☐	☐	☐	☐
PS	☐	☐	☐	☐	☐	☐
PC	☐	☐	☐	☐	☐	☐
PUR	☐	☐	☐	☐	☐	☐
PA	☐	☐	☐	☐	☐	☐
Nitrile rubbers	☐	☐	☐	☐	☐	☐
PLA	☐	☐	☐	☐	☐	☐
Don't know - they are just all referred to as plastics	☐	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐	☐

8. Please provide an estimate of the plastic waste types generated in the **wards monthly.** *

	Less than 25kg	25-50 kg	51-75 kg	75-100kg	Above 100kg	Don't know
PET/PETE	☐	☐	☐	☐	☐	☐
HDPE	☐	☐	☐	☐	☐	☐
PVC	☐	☐	☐	☐	☐	☐
LDPE	☐	☐	☐	☐	☐	☐
PP	☐	☐	☐	☐	☐	☐
PS	☐	☐	☐	☐	☐	☐
PC	☐	☐	☐	☐	☐	☐
PUR	☐	☐	☐	☐	☐	☐
PA	☐	☐	☐	☐	☐	☐
Nitrile rubbers	☐	☐	☐	☐	☐	☐
PLA	☐	☐	☐	☐	☐	☐
Don't know - they are just all referred to as plastics	☐	☐	☐	☐	☐	☐
Others, please specify	☐	☐	☐	☐	☐	☐


D. Feedback

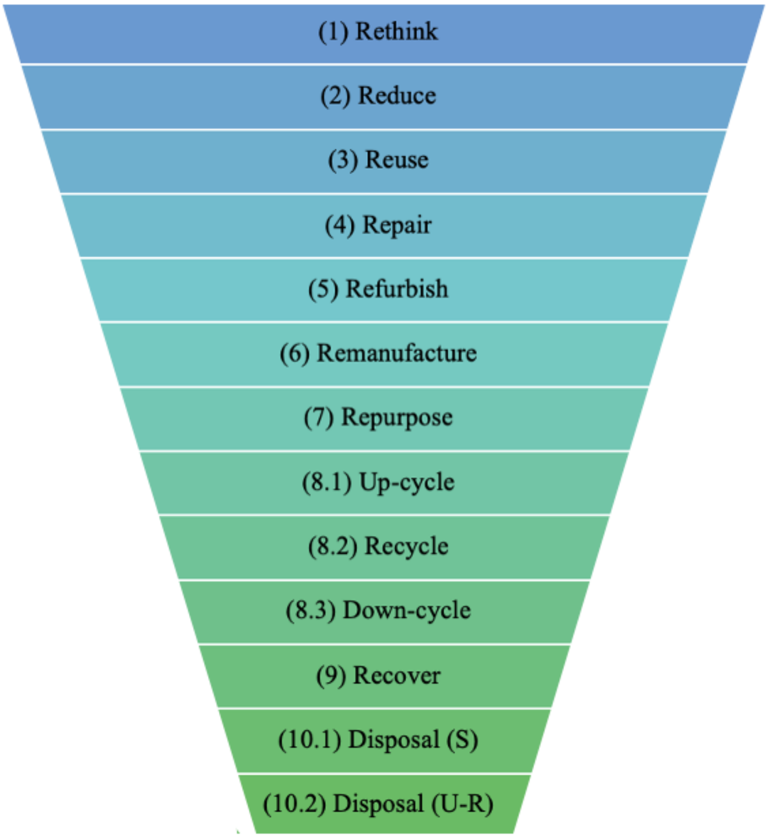
Please provide any comments or suggestions for the further improvement of this tool.

Meine Antwort

3.2 Analytical Framework

The Waste Hierarchy- Technology Readiness Levels (WH-TRL) Framework, developed by Fletcher et al. (2021, 4), is based on the combined concepts of Waste Hierarchy and Technology Readiness Levels wherein waste management technologies and strategies are assessed in terms of their readiness for implementation and contribution to circular economy based on their position on the waste hierarchy and technology maturity framework. The Waste Hierarchy principle is a scheme to rank the environmental- friendliness of waste management strategies and technologies (UK Department for Environment, Food and Rural Affairs 2011, 3) with the goal of waste minimization and preventing progressing towards the treatment and disposal stages, prioritizing waste reduction, recycling, and reuse (Pires and Martinho, 2019, 298). In this study, the Waste Hierarchy framework (Figure 4) of Fletcher et al. (2021, 4) will be adopted, which is a ten- point ranking developed by expanding the conventional five- level ranking (Figure 5) to further reflect specific circular economy and plastic recycling principles. Specifically, the expanded waste hierarchy differentiates value retention in the recycling method and disposal. In this framework, open- loop recycling, down-cycling, is not preferred as the value of the material is reduced or degraded. Moreover, the framework denotes between disposal to sanitary landfill and unregulated open dumpsites.

Figure 4. Expanded waste hierarchy



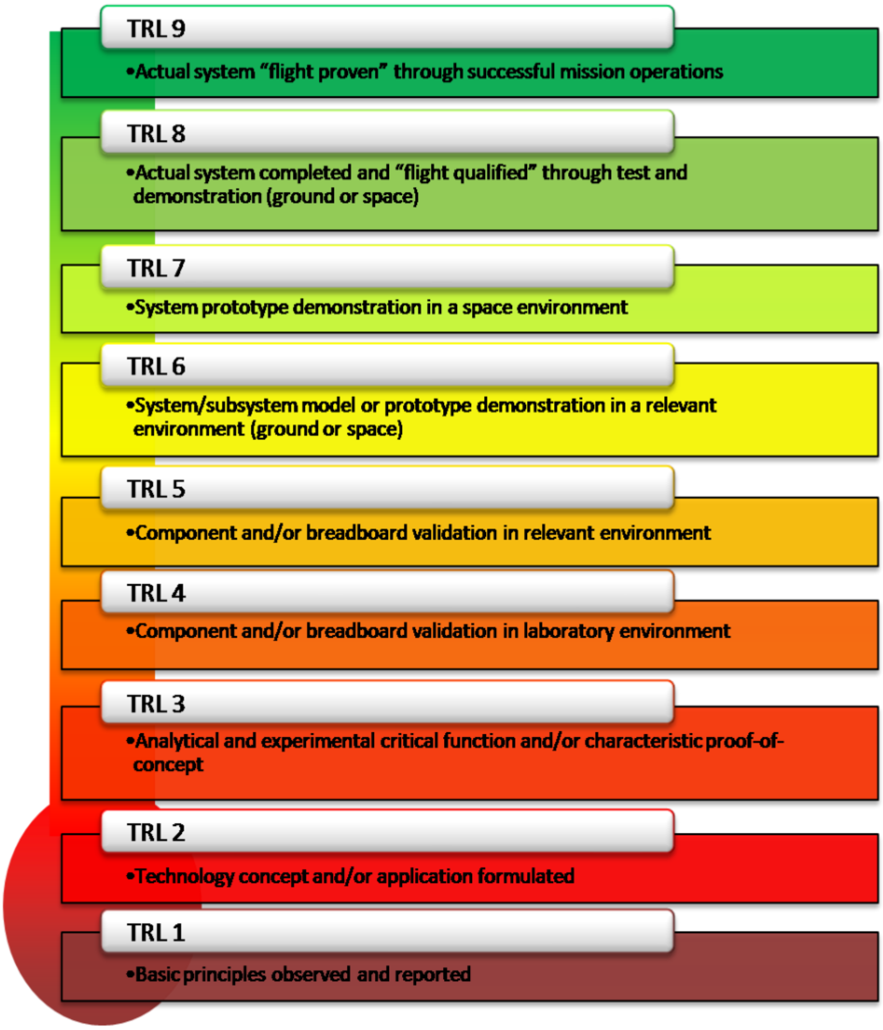
Source: Fletcher et al. 2021

Figure 5. Waste hierarchy

Source: European Commission 2017

The Technology Readiness Level (TRL) framework is a tool to measure the relative maturity of a technology for deployment to end- users to serve its ultimate purpose, from the ideation phase or conceptualization to commercialization. The TRL Framework has been used in various industries and may be employed to understand the existing capacities of the technology or product, as well as its potential for further development and the resources entailed (Rybicka et al. 2016, 1005). The TRL framework has nine levels, with one as the most basic and nine as the most advanced. The description for each level is summarized in Figure 6. In this study, the TRL framework level to be functional in waste management starts at level six, where the ''system/subsystem model or prototype demonstration in a relevant environment (ground or space).'' TRL level five is not deemed to be ready for deployment as the component/s technology are still assessed at this stage.

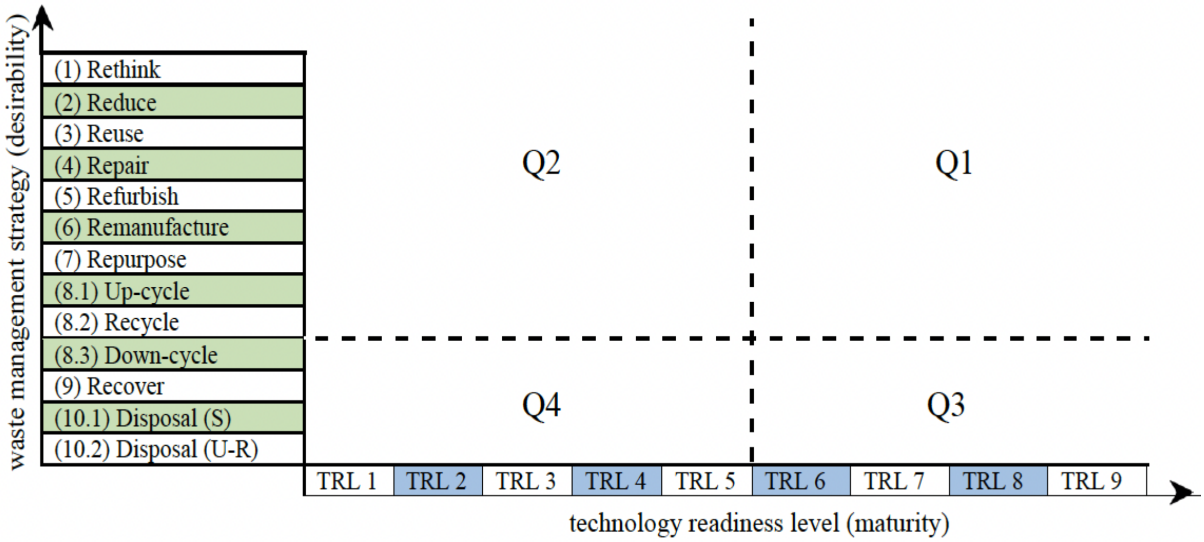
Figure 6. Technology readiness level (TRL) framework



Source: National Aeronautics and Space Administration 2012

The Waste Hierarchy- Technology Readiness Levels (WH-TRL) Framework, combining the aforementioned frameworks, has been used in this study to review the maturity and desirability in terms of circularity of the waste management technologies in the Philippines. The WH-TRL framework (Figure 7) is a cartesian plane where the x-axis is the technology readiness level (TRL) which increases from left to right, and the waste management hierarchy in the y- axis, increasing from bottom to top. The WH-TRL framework has been divided into four quadrants, to denote the relative idealness of the technology for waste management, in terms of technology maturity and waste minimization potential. It should be noted that the most mature technology is at TRL level nine (9) and the most preferred waste hierarchy is the top, or level 1, the Rethink phase where the product still serves its purpose and is still not regarded as waste. In this study, the desired TRL is at level six (6) and the waste hierarchy at recycling, so as to retain the value of the material. Hence, broken lines had been placed to serve as guide to understanding the maturity and desirability of the technologies. Quadrant one (Q1), the most desired quadrant, is characterized with the most circularity as the technology or strategy follows the circular economy principles and is fully functional and present in commercial landscapes. Quadrant two (Q2) consists of technologies with high environmental and innovation potential, where they are aligned with circular economy and are high in the waste hierarchy but are early stages of development. Quadrant three (Q3) is comprised of technologies which are low in the waste hierarchy with low circularity but are highly advanced in terms of development. Technologies in Q3 are commercially available but a re-think is needed as to be aligned with the goal of waste minimization and give way to more desired options high in the waste hierarchy. Quadrant four (Q4) is least preferred with technologies that are not viable which are neither aligned with circular economy principles nor developed for deployment.

Figure 7. Waste Hierarchy- Technology Readiness Levels (WH-TRL) Framework



Source: Fletcher et al. 2021

3.3 Data Analyses

In this study, the use of the waste management technologies listed by the Department of Health had been validated through the Plastic Waste and Sustainability Assessment Tool. The available waste management technologies had been analyzed using the WH-TRL framework based on the results of the studies of Fletcher et al. (2021) and Rybicka et al. (2016) which had been validated by groups of experts. The respondent demographics on plastic waste management and sustainability practices had also been reported.

4 Results

The fifteen respondents from the five COVID-19 referral hospitals in the National Capital Region are mostly (50%) in the 18- to 35-year-old age bracket (Figure 8) and are predominantly male (93.8%) (Figure 9). Majority of the respondents have six to ten years of experience working in the health care sector (Figure 10).

Figure 8. Age demographics of the respondents

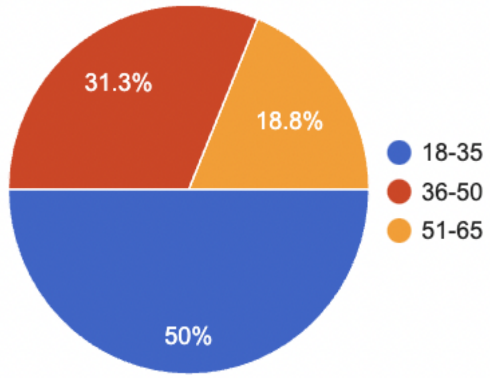


Figure 9. Gender demographics of the respondents

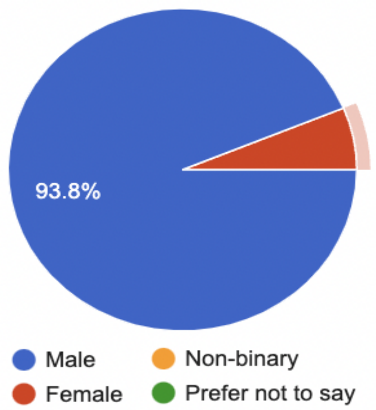
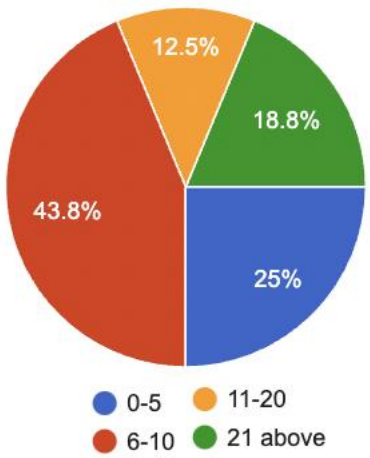


Figure 10. Respondents' length of experience in the health care sector



It has been found that 87.5% of the respondents agree that they have in-house Waste Management Committee (Figure 11) in their respective hospitals with written guidelines on the roles and responsibilities (Figure 12). Half of the respondents agree that the hospital conduct training on waste management (Figure 13) annually while 18.8% agree that trainings are done quarterly and 12.5% are not aware of the conduct of these trainings (Figure 14). Meanwhile, majority (62.5%) of the hospitals do not have established in-house Sustainability

Committee (Figure 15) with no known written guidelines or roles and responsibilities (Figure 16). According to the majority of respondents (43.8%), there has not been a training on sustainability for hospital staff while 25% are not aware (Figure 17).

Figure 11. Presence of a Waste Management Committee in their hospital affiliation

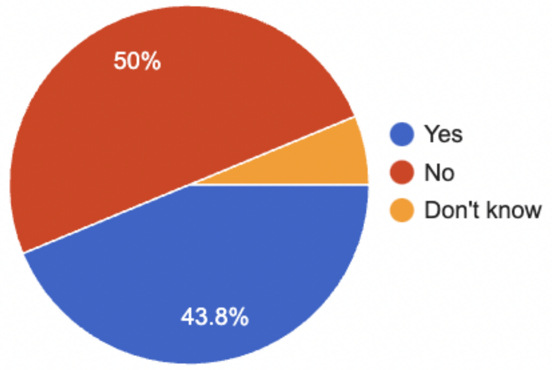


Figure 12. Presence of written roles and responsibilities or guidelines for the Waste Management Committee

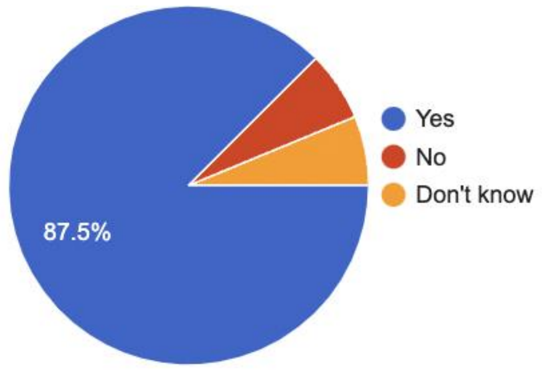


Figure 13. Presence of waste management training in the hospital

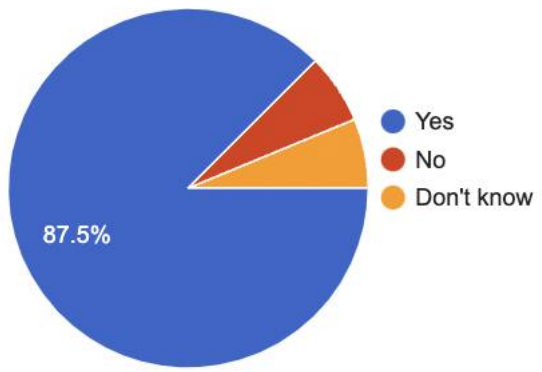


Figure 14. Frequency of waste management training in the hospital

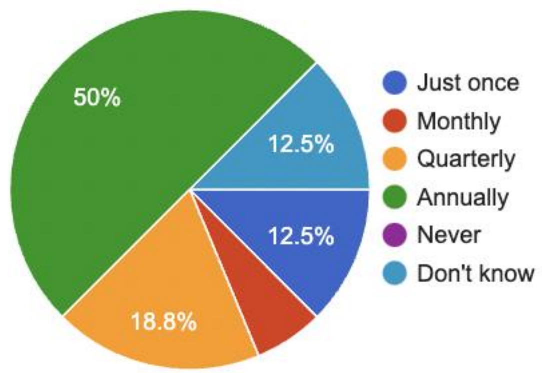


Figure 15. Existence of Sustainability Committee in the hospital

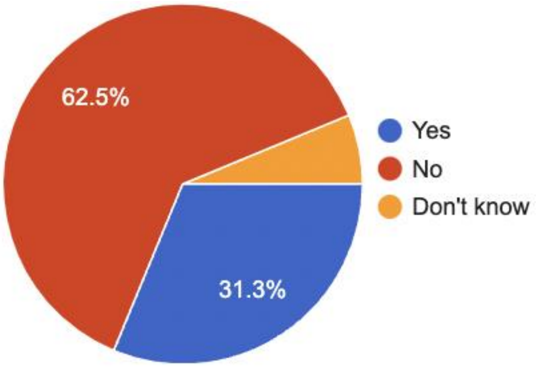


Figure 16. Existence of written roles and responsibilities or guidelines for the Sustainability Committee

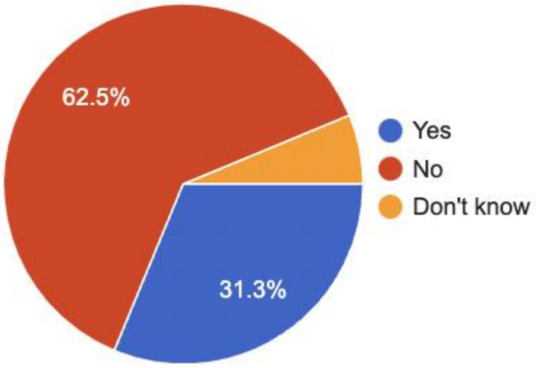
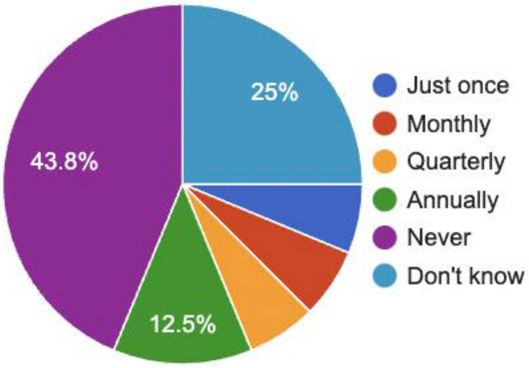


Figure 17. Frequency of sustainability training in the hospital



There is a disagreement on the existence of a policy or guideline on Green Procurement, with 43.8% of the respondents say that their hospital have and also 43.8% saying that they have none (Figure 18). Half of the respondents concur that their hospital practices the purchase of environmentally- friendly products, i.e., eco-labelled following ISO 14023, while 31.3% are not aware (Figure 19). Majority of the respondents agree that their hospital staff have not received training on green procurement (31.3%), while 25% are not aware (Figure 20). Almost half of the respondents (43.8%) are able to identify eco- labels while 37.5% are not and 18.8% are not aware (Figure 21). Based on the results of the assessment, majority of the hospitals have information, education and communication (IEC) materials for hospital staff (Figure 22) on waste management and water and energy efficiency and conservation. Meanwhile, only IEC materials on waste management are available for patients and visitors while there is mostly none on energy and water efficiency and conservation (Figure 23).

and patients and visitors.

Figure 18. Existence of policy or guideline on green procurement

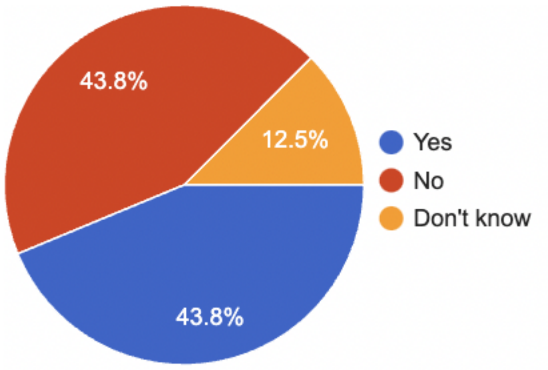


Figure 19. Hospital practice on the purchase of environmentally- friendly products

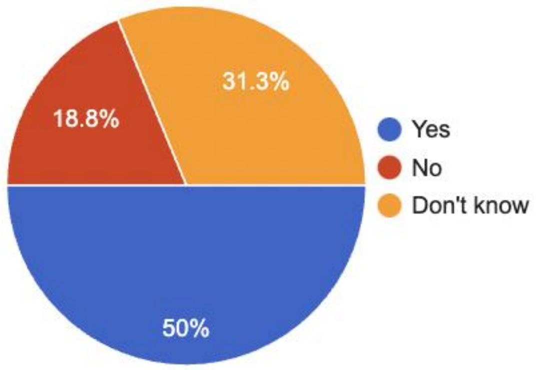


Figure 20. Frequency of green procurement training in the hospital

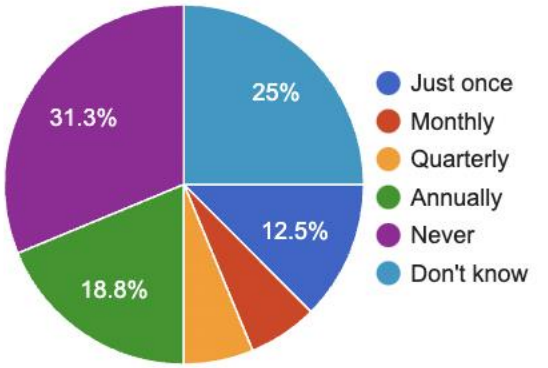


Figure 21. Percentage on the ability of the respondents to identify eco-labels

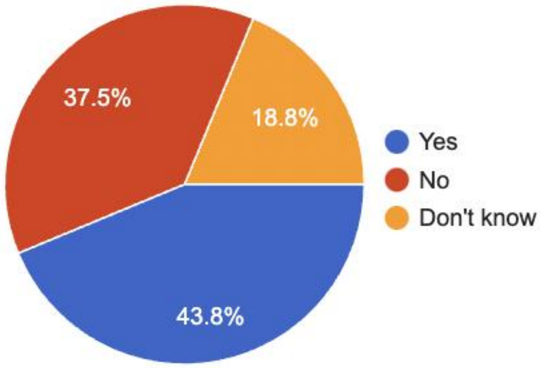


Figure 22. Existence of IEC materials on waste management and water and energy efficiency for hospital staff

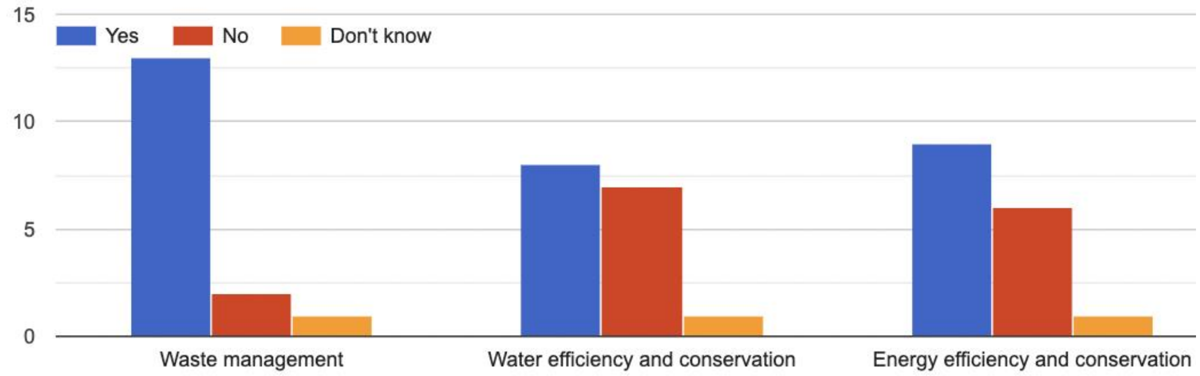
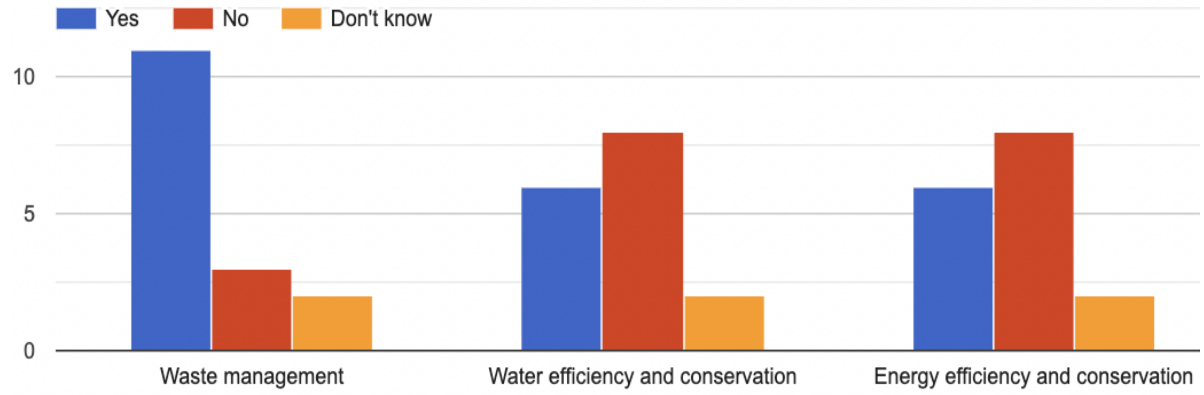


Figure 23. Existence of IEC materials on waste management and water and energy efficiency for patients and visitors



Majority of the hospitals (68.8%) have at least one onsite waste treatment technology (Figure 24), with autoclave (68.8%) and chemical disinfection (43.8%) as the most commonly used technologies (Figure 26). Most of the hospitals (75%) have a service contract with offsite waste treatment, storage, and disposal (TSD) facilities (Figure 25). Autoclave is the most commonly used technology (43.8%) by TSD facilities, followed by pyrolysis (18.8%), autoclave with shredder (12.5%), and burial in sanitary landfills (12.5%) (Figure 27). It should be noted that 12.5% of the respondents are uncertain on the technologies used by the TSD facilities and that incineration is not practiced in the Philippines.

Figure 24. Existence of onsite waste treatment technology in the hospital

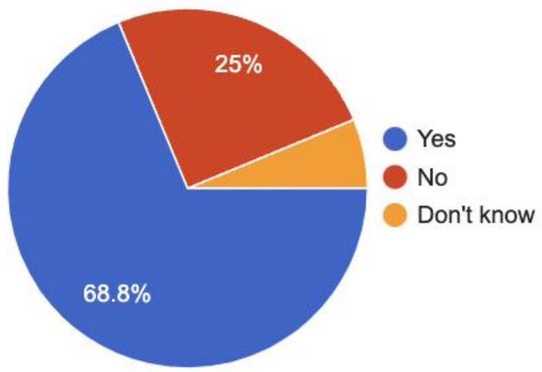


Figure 25. Existence of offsite waste treatment, storage, and disposal (TSD) service provider

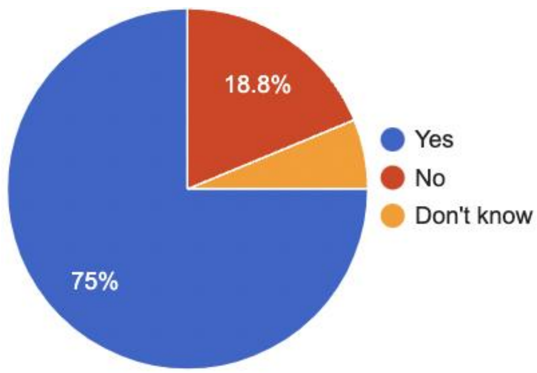


Figure 26. Waste treatment technologies utilized in the hospital

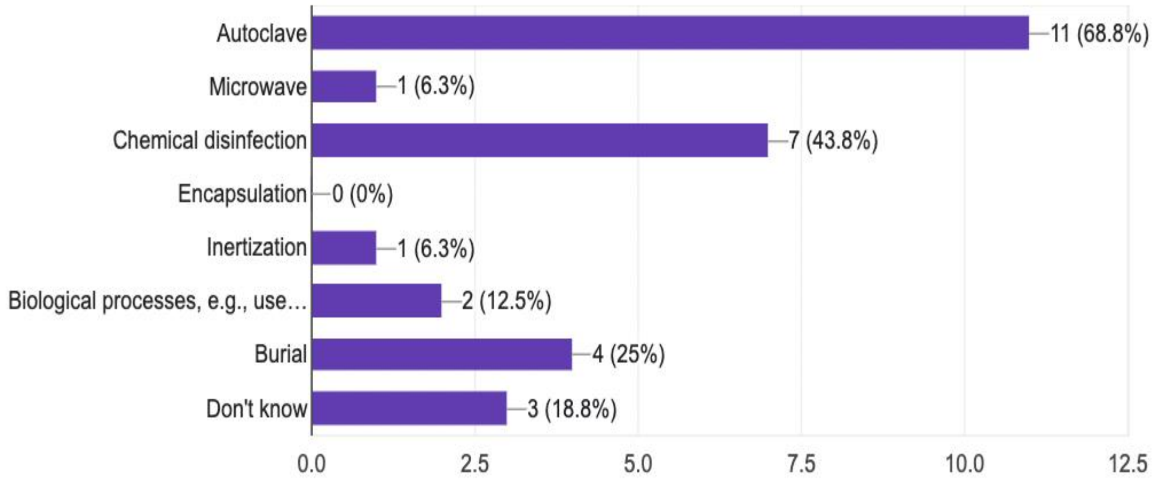
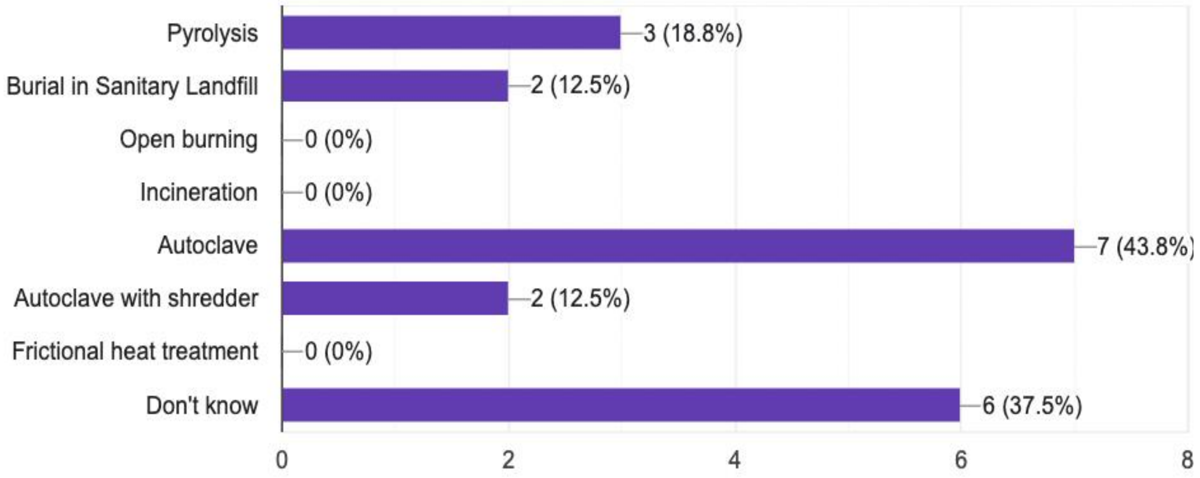


Figure 27. Waste treatment technologies utilized by waste TSD providers



According to the majority of the respondents (81.3%), their hospital affiliations have energy-saving lighting such as the use of light-emitting diode (LED) lights and maximized natural daylight (Figure 28). On the other hand, majority of the hospitals (56.3%) have no facility or equipment for the harvest and storage of alternative energy sources, e.g., solar panel (Figure 29). It has been found that 43.8% of the hospitals have or rent solar panels as alternative energy sources, while 56.3% are not knowledgeable (Figure 30). The majority of the respondents (68.8%) agree that their hospitals maximize the use of natural lighting or daylight to decrease the energy consumption and the need for light bulbs, such as through windows (Figure 31). Meanwhile, 56.3% agree that their hospitals have energy- efficient ventilation and cooling (Figure 32). The following technologies are utilized by the hospitals for ventilation and cooling (Figure 33): air conditioning unit (93.8%), electric fans (87.5%), exhaust fans (81.3%), roof insulation (68.8%), and natural ventilation such as windows and high- ceiling hall (68.8%). Lastly, 93.8% of the hospitals have a power generator in case of power outages in order to continue operations (Figure 34).

Figure 28. Hospital use of energy- saving lighting

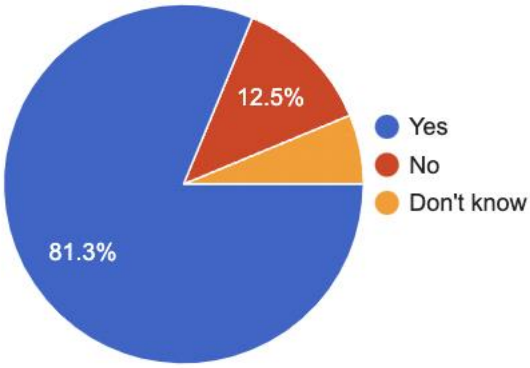


Figure 29. Existence of facility/equipment for harvesting and storing alternative energy sources in the hospital

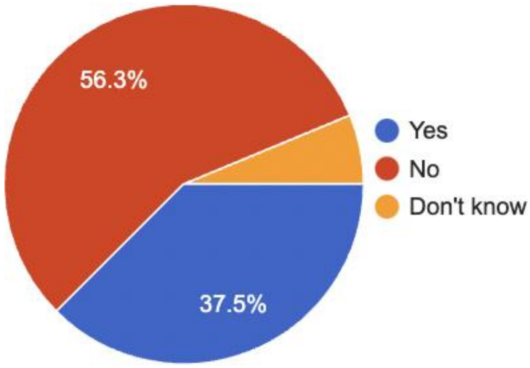


Figure 30. Owned or rented alternative energy sources of the hospitals

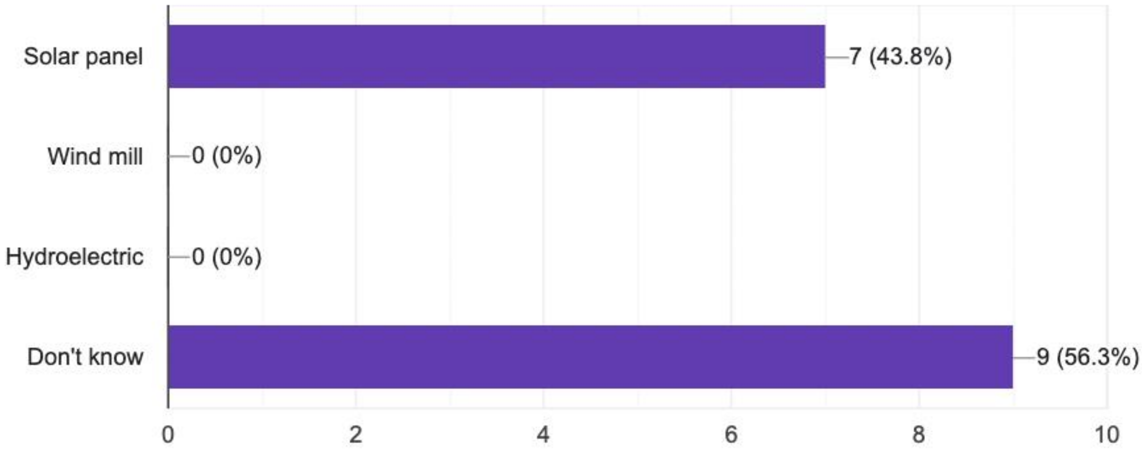


Figure 31. Hospital use of maximized natural lighting to decrease energy consumption

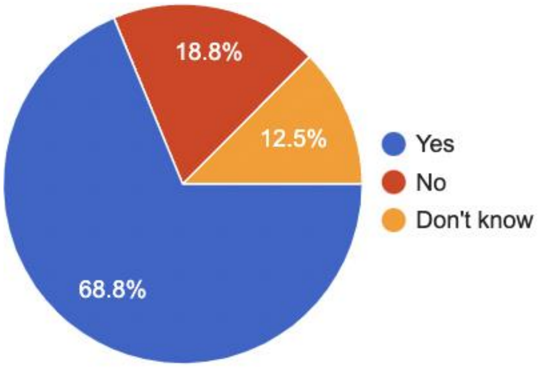


Figure 32. Hospital use of energy- efficient ventilation and cooling

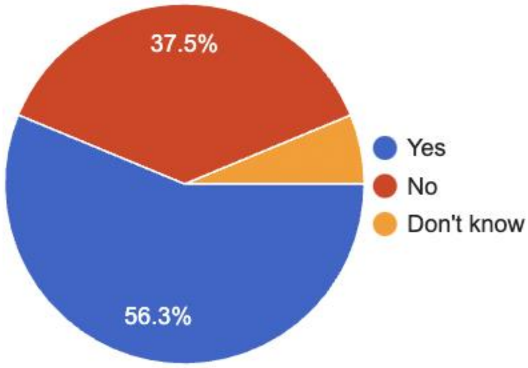


Figure 33. Technologies utilized by the hospitals for ventilation and cooling

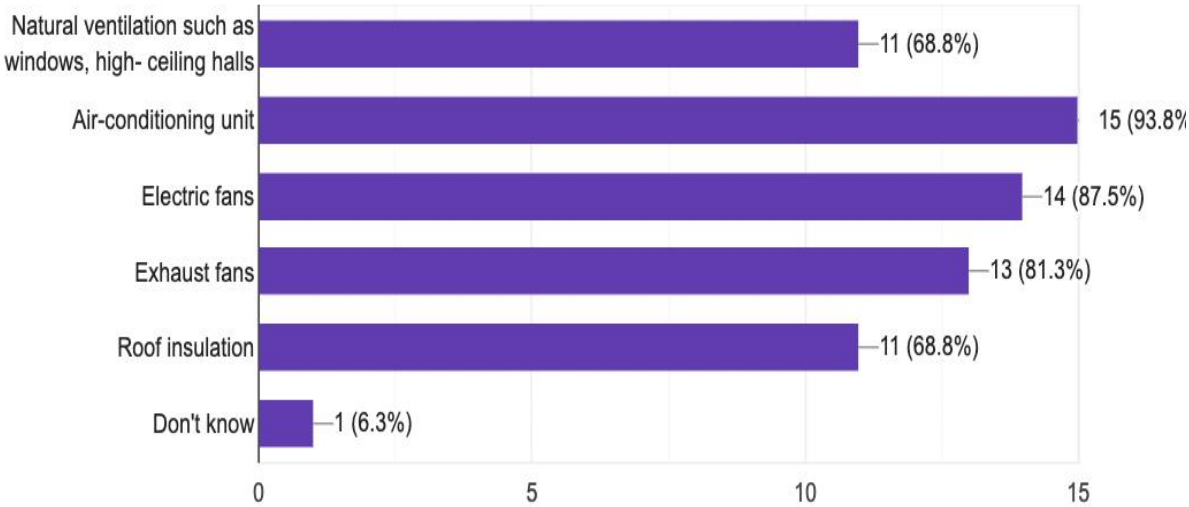
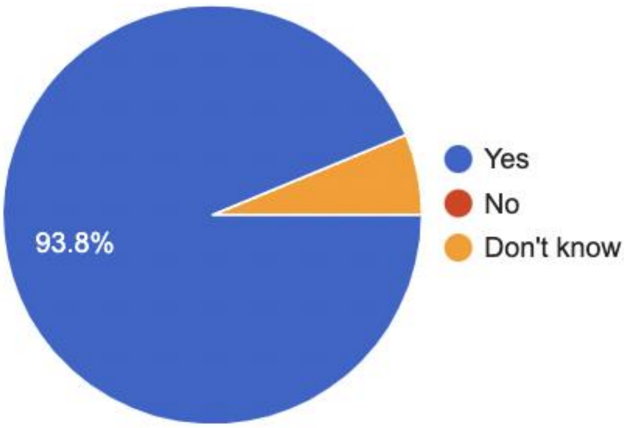


Figure 34. Existence of generators for power outages



Majority of the hospitals surveyed have infrastructure and facilities for safe drinking- water supply (62.5%) and basic handwashing facilities (87.5%) in all service areas in accordance with the standards of the World Health Organization, as shown in Figures 35 and 36, respectively. Half of the hospitals do not have a rainwater collection system (Figure 37) while 75% of the hospitals have plumbing connection system to a sewage treatment (Figure 38).

Figure 35. Presence of infrastructure and facilities for safe drinking- water supply in all service area

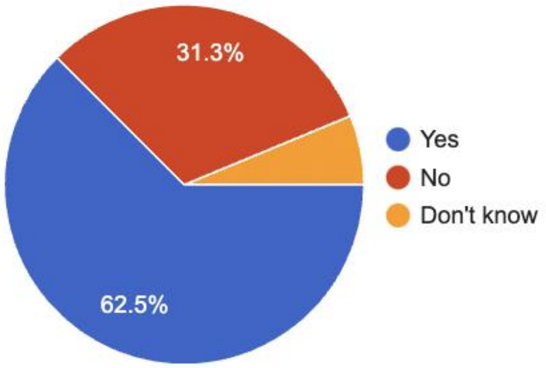


Figure 36. Presence of basic hand washing facilities in all service areas

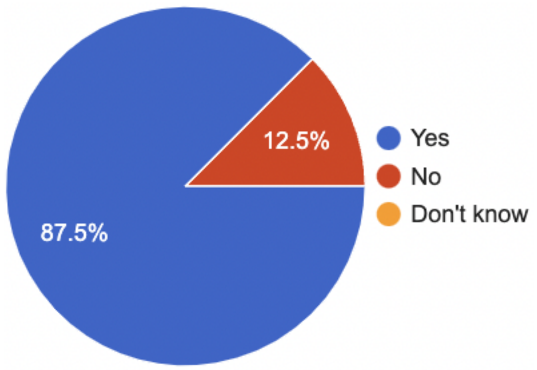


Figure 37. Presence of a rainwater collection system in the hospital

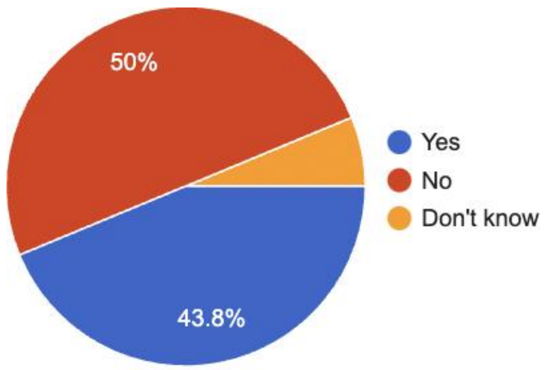
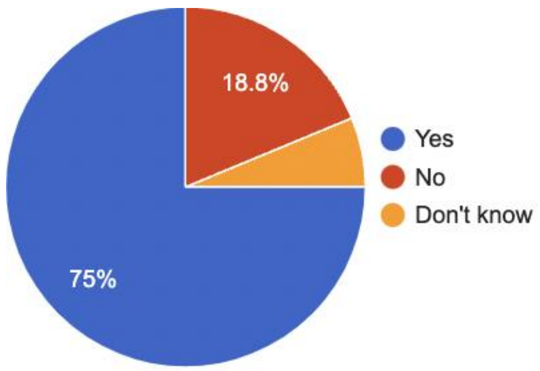


Figure 38. Presence of a plumbing connection system to a sewage treatment in the hospital



In this study, it has been found that 62.5% of the hospitals do not conduct a waste audit while 31.3% do (Figure 39). Based on the assessment, 31.3% of the hospitals conduct a waste audit annually while 18.8% has never done an audit (Figure 40). Similarly, 81.3% of the hospitals do not categorize plastic wastes into reusable and non-reusable, e.g., plastic bottles are reusable while syringes are non-reusable and must be disposed of due to their infectious nature, as shown in Figure 41.

Figure 39. Conduct of waste audit in the hospitals

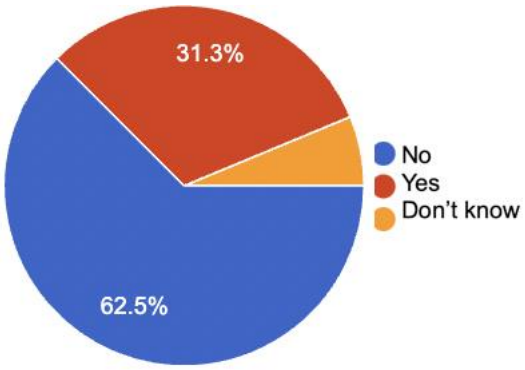


Figure 40. Frequency of waste audit in the hospitals

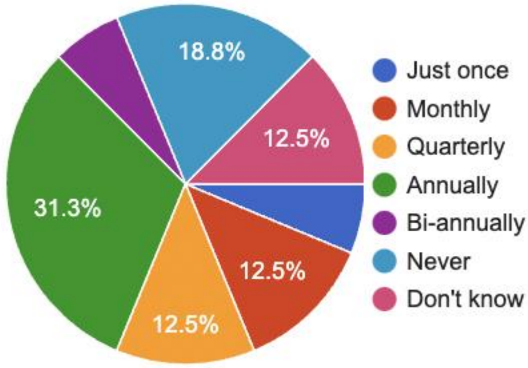
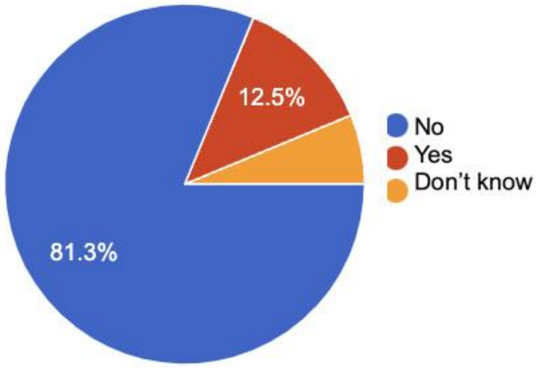
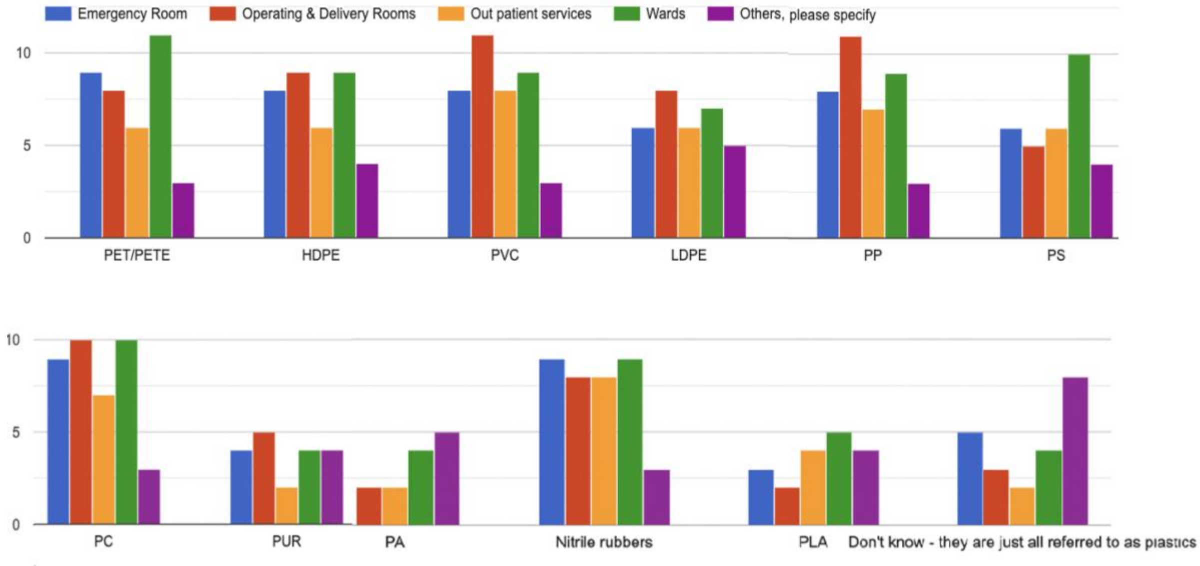


Figure 41. Sorting practice of hospitals on plastic wastes into reusable and reusable



In the Plastic Waste and Sustainability Assessment Tool, the respondents had also been asked to identify the plastic wastes with examples given (Table 1), generated per service area, emergency room, operating and delivery rooms, out- patient services, wards, etc. It should be noted that the 'Others' area pertain to common areas in the hospital such as hallways, lobbies, and visitor areas. Figure 42 below shows the which service area generates the most type of plastic waste, categorized according to the plastic resin type. Polyethylene terephthalate or polyester (PET/PETE) and polystyrene and expanded polystyrene or styrofoam are generated mostly in wards while high-density polyethylene or HDPEs and polycarbonates (PC) wastes are most commonly produced in emergency rooms and operating and delivery rooms. Polyvinyl chloride (PVC), low-density polyethylene (LDPE), and polypropylene (PP) wastes are mostly generated in operating and delivery rooms. Nitrile rubbers, on the other hand, are found almost equally in all service areas. Meanwhile, plastic types such as polyurethane (PUR), polyamide (PA), and polylactide (PLA) wastes are produced in low quantities. It should also be noted that respondents also indicated that they are at times not aware of the type of plastic waste and they are just all referred to as ‘plastic waste.’

Figure 42. Plastic waste types generated per service area



The estimated monthly production of plastic waste types in the emergency room, operating and delivery rooms, and outpatient services are mostly less than 25 kilograms, as shown in Figures 43, 44, and 45, respectively. It should be noted that most respondents do not categorize the plastics and treat them all the same as plastic waste.

Figure 43. Volume of waste types generated in the emergency room per plastic type

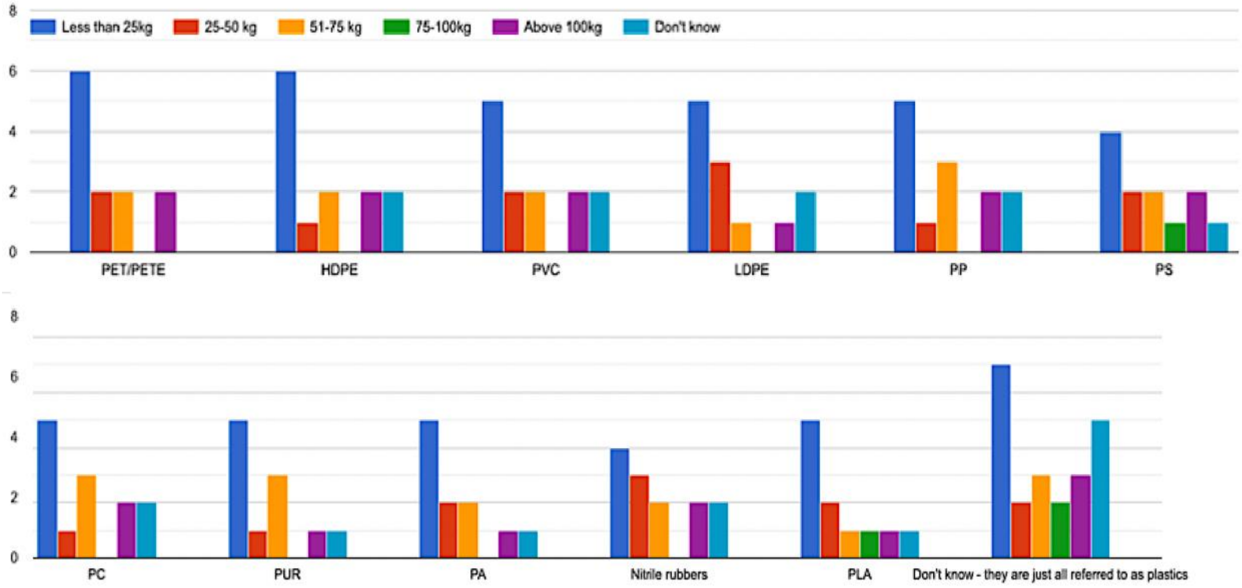


Figure 44. Volume of waste types generated in the operating and delivery rooms per plastic type

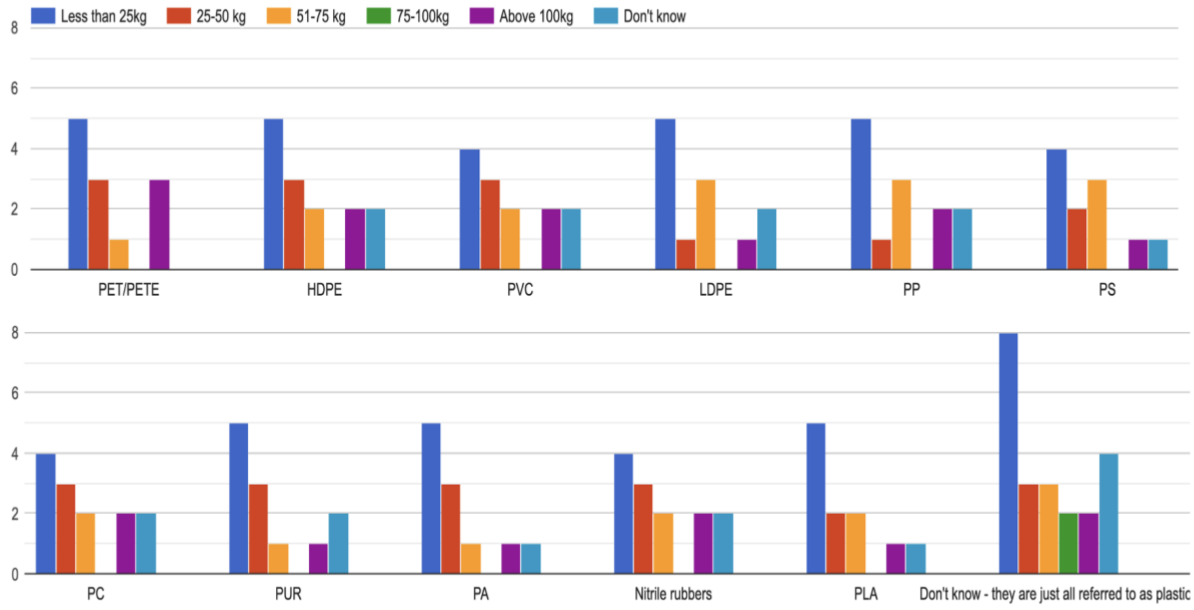
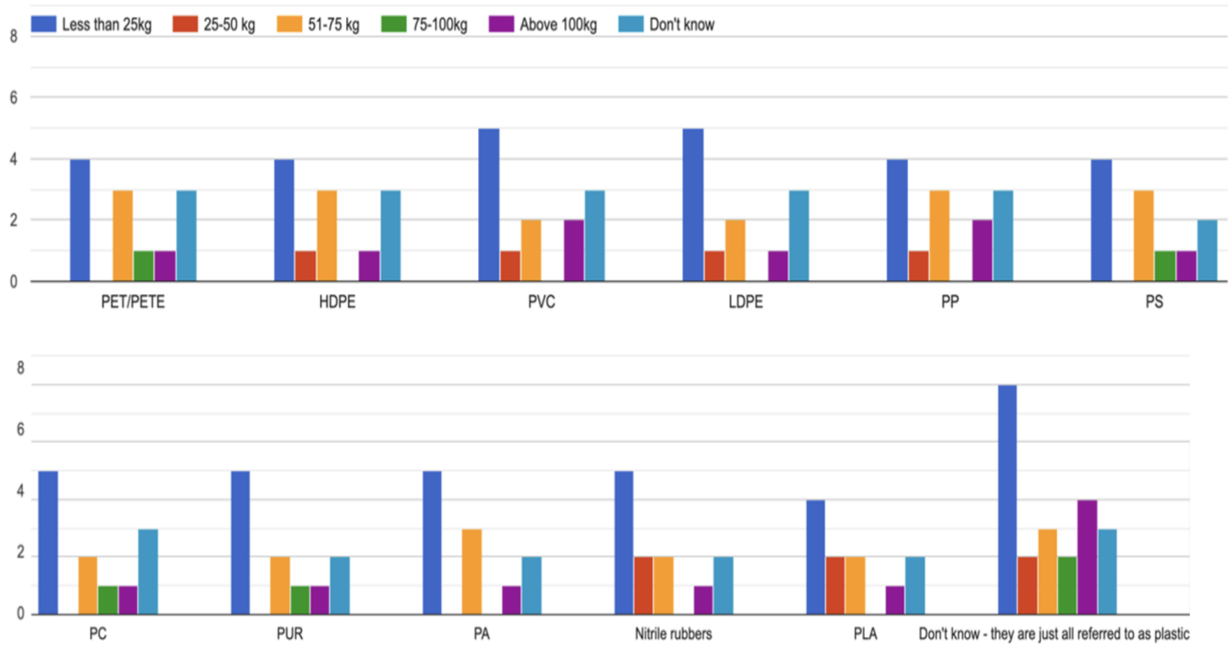
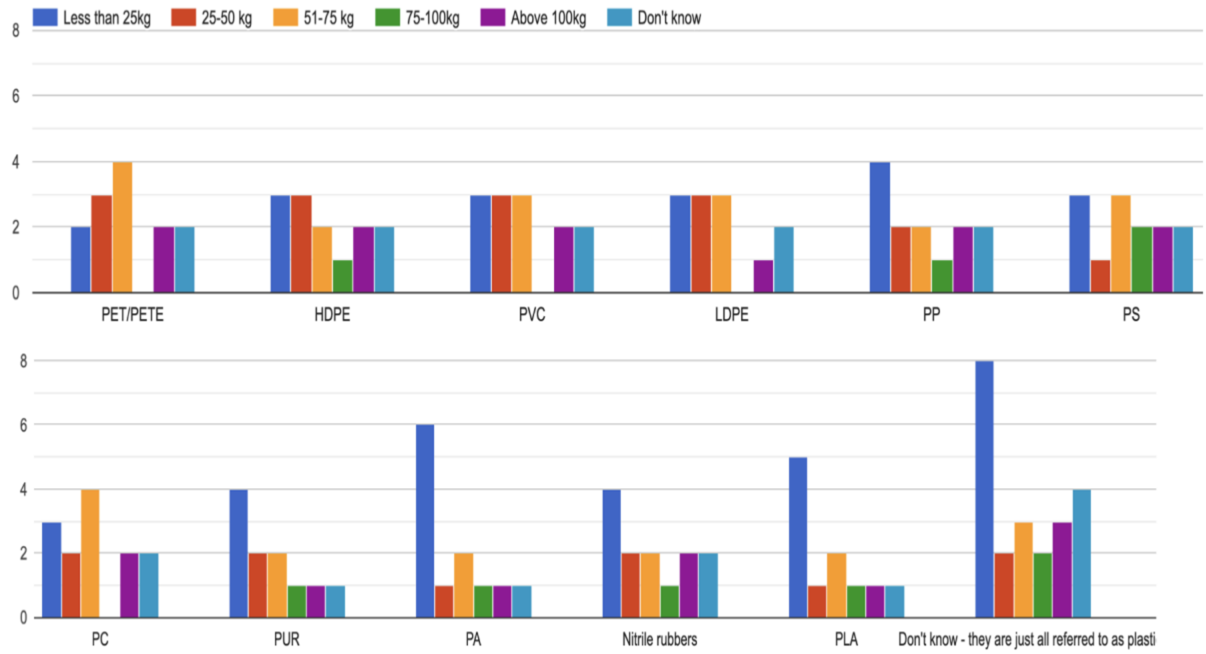


Figure 45. Volume of waste types generated in the outpatient services per plastic type



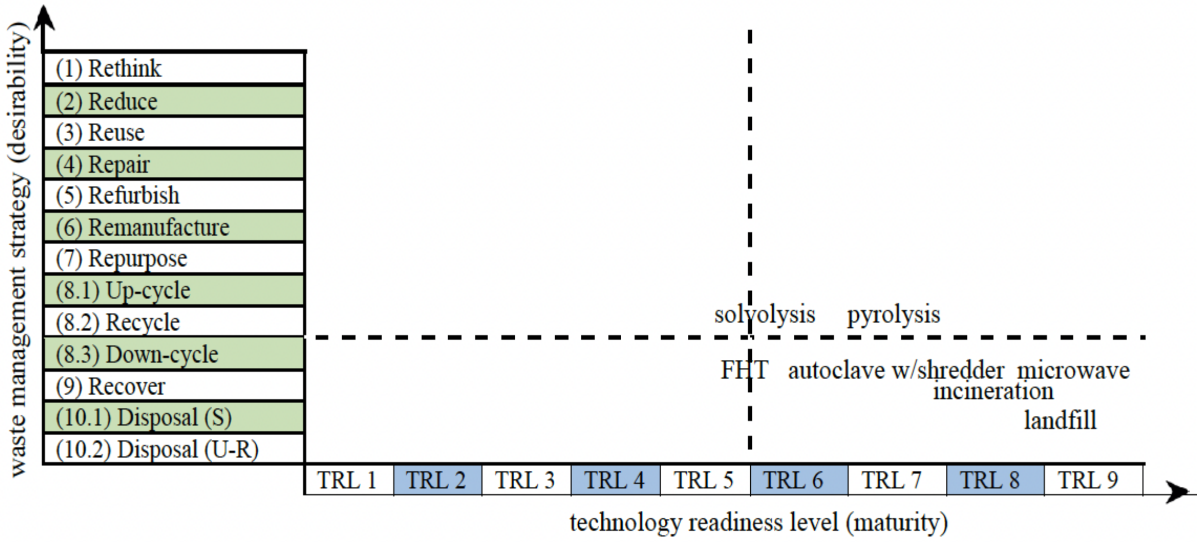
In the wards service area (Figure 46), the generation of PET/PETE, HDPE, PVC, LDPE, and PC are mostly between 25 to 75 kilograms monthly. The production of PP, PS, PUR, PA, PLA, and nitrile rubbers are mostly below 25kg per month. It should also be noted that several respondents answered that they do not categorize them and just refer to collectively as plastic waste.

Figure 46. Volume of waste types generated in the wards per plastic type



The following waste treatment and disposal technologies had been determined as the most widely used waste treatment and disposal technologies in the Philippines based on the recommendations of the Department of Health (2021) and the firsthand data from the respondents of the Plastic Waste and Sustainability Assessment Tool: pyrolysis, landfill, incineration, autoclave, autoclave with shredder, microwave, frictional heat treatment, and solvolysis. With reference to the findings of Fletcher et al. (2021) and Rybicka et al. (2016), the said waste treatment and disposal technologies had been analyzed through the waste hierarchy- technology readiness level (WH-TRL) framework, as shown in Figure 47 below. Disposal to sanitary landfills had been categorized under technology readiness level (TRL) 8.5 and waste hierarchy 10.1 or disposal (S) The S in waste hierarchy 10.1 denotes that it is disposal to sanitary landfill, in contrast with category 10.2 which is disposal to unregulated dumpsites. Incineration is categorized under TRL 7.5 and waste hierarchy 9 or recovery. Frictional heat treatment (FHT), autoclave with shredder, and microwave were all categorized under waste hierarchy 8.3 or down- cycle. FHT is placed under TRL 5.5, autoclave with shredder under TRL 6.5, and microwave under TRL 8.5. Solvolysis and pyrolysis were categorized higher in the waste hierarchy, under 8.2 or recycle. Solvolysis was determined to be fitting in TRL 6 while pyrolysis under TRL 7.5.

Figure 47. Waste hierarchy- technology readiness level (WH-TRL) analysis of waste treatment and disposal technologies in the Philippines



5 Discussion

5.1 Waste hierarchy- technology readiness level (WH-TRL)

The most commonly used waste treatment and disposal technologies in the Philippine hospitals based on the responses on the Plastic Waste and Sustainability Assessment Tool had been plotted in the waste hierarchy- technology readiness level (WH-TRL) chart in Figure 47 above. The position of the technologies in the waste hierarchy scale in the y-axis (vertical) and in the technology readiness level scale in the x-axis had been determined using the results of the studies of Fletcher et al. (2021) and Rybicka et al. (2016). Both studies have conducted literature review on the use of the waste treatment and disposal technologies on waste recycling, and Rybicka et al. (2016) performed a Delphi polling or blind expert opinion in formulating the position of these technologies in the WH-TRL scale. It should be noted that the desirability of the technology, or its alignment with the circular economy principles increases from bottom to top, with 1 or Rethink as the best solution, while 10.2 or Disposal U-R (unregulated dumpsite) as the least preferred and in the bottom of the scale and cartesian plane, as the material loses its value and did not increase its lifecycle. Meanwhile, the maturity of the technology or its readiness to be deployed to end- users to serve its intended purpose, increases from left to right in the WH-TRL scale, with TRL 1 as the lowest, and TRL 9 as the most developed technology. It should also be noted that the WH-TRL scale is divided into four quadrants, as shown in Figure 7. The broken lines in the WH-TRL scale serves as guide in interpreting the desirability and maturity of the technologies. Waste hierarchy levels Down- cycle (8.3) to Disposal U-R (10.2) are not desired as they degrade or diminish the original value of the material, and TRL levels one to five (1 to 5) are not preferred as they are in their early stages and not ready for deployment as end- products or technologies. Hence, technologies in quadrant 1 (Q1) are the technologies with highest potential in recycling in great quantities and range of users. Quadrant 2 (Q2) technologies are also of high potential for circularity but in early stages of developments, while technologies in Q3 are mature and widely deployed to end- users but need to be further improved in terms of recycling and alignment with circular economy principles. Technologies in quadrant four (Q4) are not viable in terms of circularity and deployability. As such, the waste treatment and disposal technologies most widely used in the Philippines which consist of pyrolysis, landfill, incineration, autoclave with shredder, microwave, frictional heat treatment, and solvolysis had been analyzed through the WH-TRL framework.

In this study, it has been found that solvolysis and pyrolysis are technologies that fall into Q1 or technologies with circularity and maturity potentials. Solvolysis and pyrolysis had been categorized in the waste hierarchy rank of 8.2 or recycle due to the by-products after the wastes had been subjected to the processes. While both technologies are further studied for scientific advancements, pyrolysis is more mature and studied as a technology with a TRL score of 7.5, while solvolysis is at TRL 6 which is relatively less studied. Pyrolysis is considered to have by-products that can be recycled. The by-product or recyclate of pyrolysis currently has limited applications but mostly with lesser value and potential than the initial value of the material (Rybicka et al. 2016). The recyclates of pyrolysis include high calorific gas, combustible oil, and solid residues (Fletcher et al. 2021). The recyclate has various use depending on the composition and quality of the initial plastic such as recycling and reuse (Rybicka et al. 2016), which include energy generation fuel and material production feedstock (Fletcher et al. 2021). While pyrolysis is well- studied and high in the TRL scale, it is not in the stage where there are no further advancements could be made, as reported in several studies in its technological development (Rybicka et al. 2016). Solvolyosis technologies are mostly in the laboratory scale at present and not widely deployed to end-users (Rybicka et al. 2016). The use of the recyclates of solvolyosis have various recycling applications but in its early stages of research (Rybicka et al. 2016), such as the production of chemicals and fibers which include carbon fiber recyclates from carbon fiber reinforced polymers (CFRP) (Morin et al. 2012, 234). However, the use of solvolyosis is not well-documented in the Philippines and is not included in the recommendations of the Department of Health and Department of Environment and Natural Resources. Hence, pyrolysis is the only technology with the most potential for circularity and maturity in the Philippine context.

The technologies mostly used fall into Q4 where the technologies are highly mature in technicality but are low in the waste hierarchy and circularity, as the value of the material is degraded or reduced when it has entered the waste stream, from 8.3 or down-cycling to 10.2 or disposal in unregulated dumpsites. The technologies in these categories are landfilling, incineration, autoclave with shredder, microwave, and frictional heat treatment. Landfilling is in waste hierarchy 10.1 or sanitary disposal and TRL 8.5. Its TRL is not at 9 while it is a disposal process, as sanitary landfilling is currently scientifically advancing, mostly on engineering and leachate control (Feng et al. 2021; Aderoju et al. 2020). Frictional heat treatment, autoclave with shredder, and microwave are of waste hierarchy 8.3 or down-cycle. The recyclates of these technologies are mostly fiber residues, from volume reduction and mechanical grinding of the original material which are disinfected through heating. While they are of the same waste hierarchy due to their down-cycled potential application of recyclates, they have different TRL levels, with microwave as the relatively mature and advanced technology and frictional heat treatment as the technology undergoing relatively more research and development (R&D). Moreover, these technologies have wide use due to their low operating costs. Meanwhile, incineration is positioned in the waste hierarchy, ranking at Recovery (9). Incineration recovers energy but not material, as such, it was not considered in recycling or down-cycling (Fletcher et al. 2021). The by-products of incineration are ash, flue gas, and heat or energy. However, incineration has been ‘banned’ in the Philippines. In the year 2000, incinerator units in the country had been recalled and were not allowed to be utilized due to the misconstrued and unclear interpretation of the Implementing Rules and Regulation of the Philippine Clean Air Act or Republic Act 8749. While the law does not explicitly ban incineration, authorities have considered the technology to be violating the Philippine Clean Air Act. The modernized versions of the incinerator such as those with scrubber technologies for a ‘cleaner’ emission had not been considered. Until today, there are no incinerators in the country due to low social acceptability and high maintenance and technology shifting cost, as the waste service providers or TSD facilities have invested in other technologies. The re-adoption of advanced incineration technologies should be further studied in order to significantly reduce the volume of wastes that end up in landfills. Currently, pyrolysis is the most commonly used technology in the country for waste treatment and disposal, both for municipal and health care wastes, prior to disposal in dumpsites and sanitary landfills, respectively.

5.2 Plastic waste management

Table 1 summarizes the categories of medical and non-medical plastics present in the health care setting with product examples, according to their resin type based on the ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification. The plastic types are as follows: polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA). In this study, medical plastics refer to those that are used directly involved in providing healthcare and might be infectious, while non-medical plastics are not supplementary accessories which are not used directly in providing care, such as those used by visitors for eating, etc. Below is a summary of plastic waste types and their classification in relation to health care provision.

Table 12. Plastic waste types and health care provision nature

Health Care Provision Nature	Plastic Type	Examples of Plastic Wastes
Medical	Polypropylene (PP)	syringes, sterilisation “blue” wrap, irrigation bottles, basins, cups and disposable items e.g., surgical masks, gowns, caps, shoe covers, drapes
	Polyvinyl chloride (PVC)	blood bags, IV bags, tubing, catheters, respiratory masks, disposable gloves
	Polycarbonate (PC)	medical tubing, catheters, incubators, syringes, blood oxygenators, baby bottles
	Polyurethane (PUR)	sponge
	Nitrile rubbers	disposable gloves
Non- Medical	Polyethylene terephthalate or polyester (PET/PETE)	water or drinks bottles, textile fabrics
	Low-density polyethylene (LDPE)	plastic bags, plastic films, other flexible packaging
	Polyamide (PA)	tea bags
	Polylactide (PLA)	coffee cup lids, yogurt pods
Both medical and non-	High-density polyethylene	milk or yogurt drink bottles, waste bags, intravenous (IV) fluid containers, syringe barrels

medical	(HDPE)	
	Polystyrene and expanded polystyrene or styrofoam (PS)	plastic cutlery, yoghurt cups, fruit and vegetable trays, clear solid packaging, test tubes, fast food packaging, packing peanuts, insulation

The knowledge and understanding on the type of plastics that exists in hospitals and their relation to healthcare provision paves way for more efficient collection, sorting, and recycling of the said plastics wastes. Medical plastics are highly likely to be infectious, hence, not to be reused and should be disposed of according to the protocol for infectious wastes, which is incineration for other countries, or pyrolysis in the case of the Philippines. Non- medical wastes are not directly related to health care and are usually related to food service. These type of plastics should be segregated from the medical wastes, as they can be reused and have a different process for recycling, such as for PET/PETE. HDPE and PS may be both medical and non-medical, and should employ a segregation scheme to categorize them as either medical or non-medical, for more efficient recycling. Infectious wastes which are usually high in volume, are not disinfected anymore in- house in the hospital but are collected by the waste TSD facilities. It should be noted that these TSD facilities are third- party waste service providers accredited by the Department of Environment and Natural Resources, providing services ranging from collection to treatment and disposal, both for municipal and health care wastes. Table 11 shows the recovery rate and recyclate application of the plastic types. PET/PETE has the highest recovery rate at 19.5%, while the second highest is only half of that of former, which is 10.3% for HDPE. The LDPE type, meanwhile, ranks third highest in recovery rate at 5.3%.

Based on the results of the Plastic Waste and Sustainability Assessment Tool, most of the hospitals (81.3%) do not segregate their plastics wastes into reusable and non-reusable (Figure 41), and are at times not aware of the type of plastics and recycling methods, and just referring to them collectively as plastics. It should be noted that medical and non-medical plastics are both existing in almost the same amounts in all of the service areas (Figures 43 to 46), whether in the emergency room, operating and delivery room, outpatient services, wards, and other common areas such as lobbies, visitor areas, and hallways. It should also be noted that for emergency room, operating and delivery room, and outpatient services, the estimated monthly production of all plastic waste types are below 25kg, while in the wards, the generation of PET/PETE, HDPE, PVC, LDPE, and PC is mostly between 25 to 75kg, and the production of PP, PS, PUR, PA, PLA, and nitrile rubbers are mostly below 25kg. Hence, it is not possible to generalize and associate the production of a type of plastic waste or its relation to care provision, i.e., medical or non-medical, to the hospital service area.

5.3 Hospital sustainability

In this study, the sustainability components assessed are waste management, energy and water efficiency, and material sustainability limited to eco-labeling. Currently, the Philippines has no policy or guidelines on sustainability in healthcare facilities. The Presidential Decree No. 1096 or the National Building Code of the Philippines and the Philippine Health Facility Development Plan (PHFDP) 2020-2040 (Department of Health Department Circular no. 2020-0412) serve as the main references on the infrastructure and operations of health facilities. In line with the PHFDP, the Green and Safe Health Facilities Manual was published by the Department of Health in September 2021 to serve as a guide on climate- proofing the health care facilities, as a means of climate change adaptation and mitigation and reducing the impact of disasters on healthcare. The said Manual has overlapping components on sustainability such as through minimization of environmental footprint of hospitals. Below is the criteria set by the Manual in determining the climate-smartness and greenness of the hospitals.

Table 13. Climate- proofing criteria for hospitals

Criterion	Compliance
Energy Efficiency	Reduction of energy consumption, use of renewable and clean energies
Water Efficiency, Sanitation and Hygiene	Adequate water, water reuse/recycling, water conservation, rainwater harvesting. Safe drinking water, proper use and maintenance of sanitary toilet facilities, functional handwashing, provision of soap and disinfectant, regular/periodic desludging of septic tanks, proper drainage system
Health Care Waste Management	Waste segregation, collection, storage, transport, treatment, proper waste disposal, recycling
Site Sustainability	Healing gardens within, fresh air, herbal plants, accessibility, existence of alternative routes
Material Sustainability	Use of sustainable materials, procurement of sustainable and recyclable products, less use of hazardous and toxic substances
Indoor Environmental Quality	Lighting, ventilation, interior design, air quality management
Environmentally Resilient Health Facility	Structural member, non-structural member, emergency and disaster preparedness plan
Governance	Leadership and management, trainings, proper implementation, commitment

Source: Green and Safe Health Facilities Manual 2021

The Plastic Waste and Sustainability Assessment Tool has revealed that several hospitals do not have their own Sustainability Committee or guidelines on reducing the overall carbon footprint of the health care facility. Based on the assessment result, personnel capacity building on sustainability, including training on eco- labelling, had not been conducted at all in several hospitals. Eco- labels are information on the ‘environmental- friendliness’ of products placed on packaging or catalogue which serve as guide for consumers in purchase decision- making. Eco- labelling of products is covered by ISO 14023 entitled ‘Environmental labels and declarations’ which is a self-declaration of the product manufacturer or distributor on the environmental claims of the product or service, including the methodologies on testing and verification. According to the UN Environment Programme (2022), eco- labels have three major categories. The ISO type I are the commonly known as the eco-labels, which provides information on the general environmental preference of the good or service based on life-cycle, based on the criteria of an unbiased third- party. The life-cycle approach may be single- or multi- attribute (United States Environmental Protection Agency 2022). The single- attribute refers to a single life cycle phase, commonly the product utilization stage, or an individual environmental issue such as emission risks. Meanwhile, the multi- attribute approach refers to the entire product lifecycle, comprised by manufacturing, utilization, maintenance, and disposal, or of various environmental issues linked to the product such as chemical safety, energy efficiency, and recycling potential. ISO Type II labels differ as they are determined by the manufacturer through self- labelling, while ISO Type III provides quantitative information through matrices similar to nutritional facts of food products. In this study, only the general ability of the participants to identify eco- labels had been evaluated, with almost half being able to identify them while the rest are unaware or are not capable of. Eco- labels are a good tool for hospital management to determine material sustainability as part of green procurement, with the aim of minimizing the carbon footprint of the hospital and with general consideration for the lifecycle of the products to be consumed and utilized inside the hospital premises.

Green procurement is the practice of purchasing goods and services with the least negative environmental impact. While the concept of green procurement in the Philippines has started in 2004 with the establishment of the Green Procurement Program to support the local suppliers with greener products, it is only in 2020 that the Steering and Technical Committees had been established to oversee its implementation. The origin of green procurement traces back to the Government Procurement Reform Act or Republic Act no. 9184 in 2003, having the Green Public Procurement Act or House Bill no. 6468 only recently established in 2022. The Philippine Green Public Procurement Roadmap has been formulated but there is no concrete action plan yet with the specific roles and responsibilities of government agencies and local authorities. In hospitals, the assessment has shown that there is no concurrence or agreement whether their hospitals have policy or guideline on green procurement. Meanwhile, half of the respondents concur that their hospital practices the purchase of environmentally- friendly products while a great number (31.3%) are uncertain or not aware. The assessment tool developed in this study however does not delve deeper on the parameters to determine the environmental compliance of products or services procured in the hospital.

The hospital subjects in this study are public hospitals funded by the government through the Department of Health, and not by local authorities such as city or district councils. Based on the assessment results, most of the hospitals use energy- efficient lighting through use of LED lights and maximized natural daylight. However, the assessment does not cover the energy consumption of the hospitals, and it is recommended to incorporate this parameter in the monitoring and evaluation of hospital operations. It has also been found in the study that the hospital subjects rely on conventional power sources and the use of renewable and alternative energy sources are not employed, since the hospitals do not have their own facility or infrastructure. Hence, it is recommended that the government facilitate public- private partnerships, in order to assist the transition of hospitals into sustainability, in aspects such as renewable energy. In terms of ventilation and cooling, technologies such as air conditioning unit, electric fans, exhaust fans, and roof insulation are being utilized by the hospitals. As the Philippines is a tropical country, there is no need for heating in hospital facilities.

The study has found that most hospitals have no rainwater collection system. The said facility has a high potential in reducing the water consumption of hospitals and recycling and repurposing rain which is very frequent in the country. It is a missed opportunity without such infrastructure. Meanwhile, most of the hospitals are able to treat their wastewater discharge to conform with the effluent standards set by the Department of Environment and Natural Resources (DENR), through wastewater plumbing connection and sewage treatment services provided by private water concessionaires. In the country, the water concessionaires are mandated to provide sewage treatment to all clients, both residential and private establishments. The effluents are regularly monitored by the DENR prior to discharge to the bodies of water. Furthermore, the safety of the drinking- water in hospitals are regularly checked and monitored by public Sanitary Inspectors.

6 Conclusion and Recommendations

The waste treatment and disposal technologies that are most widely utilized based on literature and the results of the Plastic Waste and Sustainability Assessment Tool include pyrolysis, landfill, incineration, autoclave, autoclave with shredder, microwave, frictional heat treatment, and solvolysis. The study has found that the several hospitals in the Philippines utilize mature technologies for waste treatment and disposal which rank high in terms of technology readiness level (TRL 7 to 8.5) in the waste hierarchy- technology readiness level (WH-TRL) framework. As the medical profession is highly sensitive and risky, establishments such as hospitals tend to be more conservative with their choice of technologies (Fletcher et al. 2021). In terms of the waste hierarchy scale, most technologies are in the range of ranks 8.2 recycle to 10.1 disposal in sanitary landfills, showing that circularity is currently low. Based on the assessment, solvolysis and pyrolysis are the technologies with the highest maturity and alignment to circular economy principles, as their byproducts or recyclates may be recycled. However, the use of solvolyosis is not well-documented in the Philippines. While incineration produces energy as a by-product which may be used for various purposes, it is currently not used in the country due to previous recall of units at the time where there was misinterpretation of the Republic Act 8749 or Philippine Clean Air Act. Further studies on the re-adoption of more advanced incineration technologies should be conducted in order to also decrease the volume of medical wastes that are disposed of in sanitary landfills. Hence, this study recommends to further conduct cost- benefit analysis on the use of pyrolysis and incineration in the treatment and disposal of healthcare wastes. It should be noted, however, that the present version of the assessment tool did not capture the technologies or techniques for waste minimization, at the phase prior to the material entering the waste stream, if any are being practiced in the hospitals.

The plastic types that are present in the hospital settings consist of polyethylene terephthalate or polyester (PET/PETE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene and expanded polystyrene or styrofoam (PS), polycarbonate (PC), polyurethane (PUR), polyamide (PA), nitrile rubbers, and polylactide (PLA), classified according to their resin identification (ASTM D7611). These plastics may be categorized according to their healthcare provision use, i.e., medical, non-medical or both, or according to their reusability. As medical wastes are highly infectious, only non- medical plastics may be reused. Medical plastics include PP, PVC, PC, PUR, and nitrile rubbers while non-medicals include PET/PETE, LDPE, PA, and PLA. Meanwhile, HDPE and PS may be both medical or non-medical. PET/PETE plastic types which may exist in the form of water or drinks bottles and textile fabrics, and PS plastic types which may include plastic cutlery, yoghurt cups, fruit and vegetable trays, clear solid packaging, test tubes, fast food packaging, packing peanuts, and insulation are the most abundant plastic waste types produced in the wards of hospitals. In both emergency rooms and operating and delivery rooms, HDPEs such as milk or yogurt drink bottles, waste bags, intravenous (IV) fluid containers, and syringe barrels and PCs such as medical tubing, catheters, incubators, syringes, blood oxygenators, and baby bottles are the most produced plastic wastes. Meanwhile, operating and delivery rooms generate PVC, LDPE, and PP the most. Furthermore, nitrile rubbers are prevalent in all service areas which may be attributed to the rise of the use of personal protective equipment or PPE in the time of COVID-19.

The assessment conducted has revealed that waste audit is not incorporated in the regular operation of Philippine hospitals. Without the knowledge of the composition and amount per type of waste generated, especially plastic wastes, recycling is made more difficult, starting from segregation at waste collection. Efficient segregation at the point of collection should be established in hospitals, guiding every staff, patient, and visitor through effective information, education and communication (IEC) materials. Non- medical plastics should be collected separately from infectious medical ones, to reduce the amount of recyclates being down-cycled or totally disposed of. Collection systems for non- medical plastics, such as bottle collection, should be established at the common areas in the hospital. The government should also campaign for a stricter extended producer responsibility (EPR) for these non-medical plastics. As the waste treatment, storage, and disposal (TSD) facilities are the designated waste service providers that process the waste of hospitals, the government must provide support into capacitating them. The government should focus on volume- reducing treatment and disposal technologies, considering the limited capacity of the sanitary landfills and to further avoid the establishment of new ones. Cost- benefit analyses studies on investing in more efficient sorting technologies, or partnership with foreign companies for non-medical plastic wastes should be explored, as sorting of the core materials of products is the key to more efficient recycling, i.e., upcycling, recycling, or down-cycling, of materials so as to prolong their use phase and consequently their lifecycle.

Hospitals must be geared toward and capacitated to transition to sustainability in order to reduce the overall carbon footprint and mitigate climate change. The sustainability practices and the alignment with circular economy principles of hospitals must be regularly assessed. Currently, there are guidelines on management and reduction of plastic wastes in hospitals. Hence, it is recommended to consider the adoption of the Plastic Waste and Sustainability Assessment Tool as a regular monitoring tool in the hospital, with improvements on the design to capture waste reduction technologies or techniques which are in waste hierarchy levels one to seven, and to integrate timescale element to track progress on waste generation, energy consumption, etc. It is also recommended to respond to the assessment tool in several groups with members from various departments of the hospital to ensure that there will be someone knowledgeable to answer all areas of hospital operations. The government through the Department of Health must invest on capacity building of hospital personnel on holistic sustainability, prioritizing waste management, energy and water efficiency, and material sustainability. Hospitals should be incentivized for sustainable practices such as conduct of green procurement and patronizing environmental- friendly, eco-labeled products. As the existing budget of hospitals are mostly allocated to patient care and medical devices, it is recommended that the private sector partake in the improvement of the energy and water efficiency of hospitals, such as through co-financing of solar panels and rainwater collection systems, in support of the transition to renewable energy and water recycling and conservation. The government must create an enabling environment and develop platforms in which hospitals, private sector, and non- government organizations can interface to support the transition of hospitals into sustainability.

7 References

Aderoju, OM, Dias, GA, and Gonçalves, AJ. 2018. "A GIS-based analysis for sanitary landfill sites in Abuja, Nigeria." *Environment, Development and Sustainability* 22: 551–574.

Alabi, OA, Ologbonjaye, KI, Awosolu, O, and Alalade, OE. 2019. "Public and Environmental Health Effects of Plastic Wastes Disposal: A Review.'' *J Toxicol Risk Assess,* 5: 021. https://doi.org/10.23937/2572-4061.151002.

Alagirusamy, R, Das, A. 2014. "2 – Yarns: Production, processability and properties." *Fibrous and Composite Materials for Civil Engineering Applications* : 29-61. https://doi.org/ 10.1533/9780857095583.1.29

Alvarez, JM. 2015. "Green procurement environmentally preferred products." Accessed May 20, 2023. https://ps-philgeps.gov.ph/home/images/BAD/merchants/ppt/GP%20and%20Ecolabelling%20by%20Mr.%20June%20M.%20Alvarez.pdf.

American National Standards Institute. 2019. ASTM D7611: Standard Practice for Coding Plastics Manufactured Articles for Resin Identification. Accessed May 20, 2023. https://blog.ansi.org/2019/02/resin-identification-codes-rics-astm-d7611/

Asian Development Bank. 2021. "Sustainable public procurement." Accessed May 20, 2023. https://www.adb.org/sites/default/files/sustainable-public-procurement.pdf.

Awaja, F, and Dumitru, P. 2005. "Recycling of PET." *European Polymer Journal* 41 (7): 1453-1477. https://doi.org/10.1016/j.eurpolymj.2005.02.005.

Bawaneh, K, Nezami, FG, Rasheduzzaman, MD, and Brad, D. 2019. "Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States." *Energies* 12 (19): 3775. https://doi.org/10.3390/en12193775.

Bourguignon, D. 2016. "Closing the loop: New circular economy package.'' Accessed May 20, 2023. https://policycommons.net/artifacts/1334448/closing-the-loop/1939999/

Britannica. 2023. “High-density polyethylene.” Accessed May 20, 2023. https://www.britannica.com/science/high-density-polyethylene.

Britannica. 2023. “Nitrile rubber.” Accessed May 20, 2023. *https://www.britannica.com/technology/nitrile-rubber*.

Brittanica. 2023. Low-density polyethylene. Accessed May 20, 2023. *https://www.britannica.com/science/low-density-polyethylene.*

Brown, N. 2023. “The Life Cycle of Plastics.” *Debris Free Oceans.* Accessed May 20, 2023. https://debrisfreeoceans.org/the-life-cycle-of-plastics.

Budd, K. 2019. “Hospitals race to save patients – and the planet” *AAMC.* Accessed May 20, 2023. https://www.aamc.org/news/hospitals-race-save-patients-and-planet.

Burra, KG and Gupta, AK. 2018. “Synergistic effects in steam gasification of combined biomass and plastic waste mixtures.’’ *Applied Energy* 211: 230-236. https://doi.org/10.1016/ j.apenergy.2017.10.130.

Centers for Disease Control and Prevention. 2015. “Infection control: Guidelines for environmental infection control in health-care facilities.” Accessed May 20, 2023. https://www.cdc.gov/infectioncontrol/guidelines/environmental/background/medicalwaste.html.

Cossu, R and Stegmann, R. 2019. Clean Development Mechanism (CDM) in Landfilling. *Solid Waste Landfilling:* 1153-1174. https://doi.org/10.1016/C2012-0-02435-0.

Cruz, C., Garcia, Colet, P.C. Cruz, J.P., and Alcantara, J.C. 2014. “Healthcare waste management of the government hospitals in northern Philippines.” *European Scientific Journal* 10 (26): 114122.

Department for Environment, Food and Rural Affairs. 2011. “Government Review of Waste Policy in England 2011.” Accessed May 20, 2023. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69401/pb13540-waste-policy-review110614.pdf.

Department for Environment, Food and Rural Affairs. 2011. "Guidance on applying the Waste Hierarchy." Accessed May 20, 2023. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69403/pb13530-waste-hierarchy-guidance.pdf.

Department of Environment and Natural Resources. 2005. *Joint DOH- DENR Administrative Order (JAO) 02 s. 2005: Policies and guidelines on effective and proper handling, collection, transport, treatment, storage and disposal of health care wastes*. Quezon City: Department of Environment and Natural Resources.

Department of Environment and Natural Resources. 2016. *National solid waste management status report 2008-2014.* Quezon City: Department of Environment and Natural Resources. https://nswmc.emb.gov.ph/wpcontent/uploads/2016/06/Solid-Wastefinaldraft-12.29.15.pdf.

Department of Environment and Natural Resources. 2021. *Infectious and pharmaceutical wastes 2019-2021.* Quezon City: Department of Environment and Natural Resources.

Department of Health. 2020. *Health care waste management manual 4th ed.* Manila: Department of Health.

Department of Health. 2021. *Green and safe health facilities manual 1st ed.* Manila: Department of Health.

Department of Health. 2022. "Summary Statistics Hospitals." Accessed May 20, 2023. https://docs.google.com/spreadsheets/d/e/2PACX-1vSrKKNMbcErl3HfqMdFmHPwTPdpGDq-m94w3nH5E5wC2mk0ge5PyfTPCayujNU6yyCOBLYNhhr_-vk/pub_html.

D'Adamo, I, Mazzanti, M, Morone, P. 2022. "Assessing the relation between waste management policies and circular economy goals." *Waste Management* 154: 27-35. https://doi.org/10.1016/j.wasman.2022.09.031Get rights and content.

Eckelman, MJ and Sherman, J. 2016. "Environmental Impacts of the U.S. Health Care System and Effects on Public Health" *PLoS One* 11 (6): e0157014. https://doi.org/10.1371/journal.pone.0157014.

Environmental Protection Agency. 2018. "Particulate matter (PM) pollution." Accessed May 20, 2023. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics.

European Commission. 2016. "Buying green! A handbook on green public procurement." Accessed May 20, 2023. https://ec.europa.eu/environment/gpp/pdf/Buying-Green-Handbook-3rd-Edition.pdf.

European Commission. 2018. "Waste prevention and management." Accessed May 20, 2023. https://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_ en.htm.

European Parliament. 2023. "Circular Economy: definition, importance, and benefits." Accessed May 20, 2023. https://www.europarl.europa.eu/news/en/headlines/economy/ 20151201STO05

Feng, SJ, Chang, JY, Zhang, XL, and Shi, H. 2021. "Stability Analysis and Control Measures of a Sanitary Landfill with High Leachate Level." *Journal of Geotechnical and Geoenvironmental Engineering* 147(10). https://doi.org/10.1061/(ASCE)GT.1943-5606.0002635.

Fletcher, CA, St. Clair, R, and Sharmina, M. 2021. "A framework for assessing the circularity and technological maturity of plastic waste management strategies in hospitals." *Journal of Cleaner Production* 306: 127169. https://doi.org/10.1016/j.jclepro.2021.127169.

Freeman, MI and Levine, SM. 2023. "Chapter 13 – Facts about glasses." *The Ophthalmic Assistant (Tenth Edition)* 207-235. https://doi.org/10.1016/B978-0-323-39477-2.00013-0.

Gallagher, K. S. 2006. “Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry.” *Energy Policy* 34 (4): 383-394.

Geyer, R, Jambeck, JR, and Law, KR. 2017. “Production, use, and fate of all plastics ever made.” *Science Advances* 3 (7). https://doi.org/10.1126/sciadv.1700782.

Health Care Climate Council. 2020. “Climate Action: A Playbook for Hospitals.” Accessed May 20, 2023. https://climatecouncil.noharm.org/

Health Care Without Harm. 2018. “Reducing the carbon footprint of healthcare through sustainable procurement.” Accessed May 20, 2023. https://noharm-europe.org/sites/default/files/documents-files/5624/2018-09-25_Reducing_carbon_ footprint_healthcare%20WEB.pdf.

Health Care Without Harm. 2019. “Healthcare waste treatment technologies database.” Accessed May 20, 2023. https://noharm-global.org/issues/global/healthcare-waste-treatment-technologies-database.

Health Care Without Harm. 2021. “Green purchasing in health care.” Accessed May 20, 2023. https://noharm.org/sites/default/files/lib/downloads/purchasing/Green_Purchasing_ Health_Care_EU.pdf.

Health Care Without Harm. 2021. “Measuring and reducing plastics in the healthcare sector.” Accessed May 20, 2023. https://noharm-europe.org/sites/default/files/documents-files/6886/2021-09-23_Measuring-and-reducing-plastics-in-the-healthcare-sector.pdf

Health Care Without Harm – Southeast Asia. 2021. “COVID-19 and medical waste management: Plastics issues during a global pandemic. A study of five hospitals in the Philippines.” Accessed May 20, 2023. https://drive.google.com/file/d/1dIVxigRRilr6 79otwTGDfgH_F6Em4rYX/view.

Hopewell, J, Dvorak, R, and Kosior E. 2009. "Plastic recycling: challenges and opportunities." https://doi.org/10.1098/rstb.2008.0311.

Kalkanis, K, Alexakis, DE, Kyriakis, E, Kiskira, K, Lorenzo-Llanes, J, Themelis, NJ and Psomopoulos, CS. 2022. "Transforming Waste to Wealth, Achieving Circular Economy." *Circular Economy and Sustainability* 2, 1541-1559 (2022). *Circular Economy and Sustainability* 2: 1541–1559.

Koerner, GR, Hsuan, YG, and Koerner, RM. 2014. "3 3 – The durability of geosynthetics." *Geosynthetics in Civil Engineering* 36-65. https://doi.org/10.1533/ 9781845692490.1.36.

Koerner, GR and Koerner, RM. 2019. "7.3 – Polymeric Geomembrane Components in Landfill Liners." *Solid Waste Landfilling: Concepts, Processes, Technologies* 313-34. https://doi.org/10.1016/B978-0-12-407721-8.00017-6.

Life Cycle Initiative. 2023. "Life Cycle Assessment in High-Impact sectors." Accessed May 20, 2023. https://www.lifecycleinitiative.org/activities/life-cycle-assessment-inhigh-impact-sectors/life-cycle-approach-to-plastic-pollution/

Li Na Ji. 2013. Study on Preparation Process and Properties of Polyethylene Terephthalate (PET)." *Applied Mechanics and Materials* 312: 406-410. https://doi.org/10.4028/www.scientific.net/AMM.312.406.

Merrington, A. 2011. "11 – Recycling of Plastics." Applied Plastics Engineering Handbook: 177-192. https://doi.org/10.1016/B978-1-4377-3514-7.10011-X.

Mohr, J, Sengupta, J, and Slater, S. 2010. *Marketing of high-technology products and innovations.* (3rd ed.) New Jersey: Pearson Education, Inc.

Morin, C, Serani, AL, Cansell, F and Aymonier, C. 2012. "Near- and supercritical solvolysis of carbon fibre reinforced polymers (CFRPs) for recycling carbon fibers as a valuable resource: State of the art." *The Journal of Supercritical Fluids* 66: 232-240. https://doi.org/10.1016/j.supflu.2012.02.001.

National Aeronautics and Space Administration. 2012. "Technology Readiness Level." Accessed May 20, 2023. https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level.

National Economic and Development Authority. 2019. ''Philippine Green Public Procurement System.'' Accessed May 20, 2023. https://www.gppb.gov.ph/downloadables/forms/GPP_roadmap_print.pdf.

National Economic and Development Authority. 2021. ''Philippine Action Plan for Sustainable Consumption and Production (PAP4SCP).'' Accessed May 20, 2023. https://sdg.neda. gov.ph/philippine-action-plan-for-sustainable-consumption-and-productionpap4scp/.

Nisticò, R. 2020. "Polyethylene terephthalate (PET) in the packaging industry." *Polymer Testing* 90: 106707. https://doi.org/10.1016/j.polymertesting.2020.106707

Pang, X, Zhuang, X, Tang, Z and Chen, X. 2010. "Polylactic acid (PLA): Research, development and industrialization." *Biotechnol J* 5: 1125-1136. https://doi.org/10.1002/biot. 201000135.

Park, S, Seo, M. 2011. "Chapter 6 – Element and Processing." *Interface Science and Technology* 18: 431-499. https://doi.org/10.1016/B978-0-12-375049-5.00006-2

Pham, NTH. 2021. "Characterization of Low-Density Polyethylene and LDPE-Based/Ehylene-Vinyl Acetate with Medium Content of Vinyl Acetate." *Polymers (Basel).* 13 (14): 2352. https://doi.org/10.3390/polym13142352.

Pichler, PP, Jaccard, IS, Weisz, U, and Weisz, H. 2019. "International comparison of health care carbon footprints." *Environ. Res. Lett.* 14: 064004. https://doi.org/10.1088/1748-9326/ab19e1.

Pires, A and Martinho, G. 2019. “Waste hierarchy index for circular economy in waste management.” *Waste Management* 95: 298-305. https://doi.org/10.1016/j.wasman.2019.06.014.

Rani, M, Meenu, and Shanker, U. 2023. “Chapter 14 – The role of nanomaterials in plastics biodegradability.” *Biodegradability of Conventional Plastics: Opportunities, Challenges, and Misconceptions* 283-3. https://doi.org/10.1016/B978-0-323-89858-4.00012-9.

Rushton, L. 2003. “Health hazards and waste management.” *British Medical Bulletin* 68 (1): 183–197. https://doi.org/10.1093/bmb/ldg034.

Rybicka, J, Tiwari, A, and Leeke, GA. 2016. “Technology readiness level assessment of composites recycling technologies.” *Journal of Cleaner Production* 112 (1): 1001-1012. https://doi.org/10.1016/j.jclepro.2015.08.104

Sauter, R. and Watson, J. 2008. “Technology leapfrogging: A review of the evidence. University of Sussex, Sussex Energy Group.” *Science and Technology Policy Research*. Accessed May 20, 2023. https://www.researchgate.net/publication/292265366_Technology_leapfrogging_a_review_of_the_evidence_University_of_Sussex_Sussex_Energy_Group.

Schilling, M.A. 2013. *Strategic management of technological innovation*. (4th ed.) New York: McGraw- Hill Companies, Inc.

Selke, S.E. 2016. “Recycling: Polymers.” *Encyclopedia of Materials: Science and Technology (Second Edition)*: 8075-8079. https://doi.org/10.1016/B0-08-043152-6/01451-0.

Shane, S. 2008. *The handbook of technology and innovation management.* England: John Wiley & Sons, Ltd.

Silva, C, Cavaco-Paulo, A, and Nierstrasz, VA. 2014. “4 - Enzymatic hydrolysis and modification of core polymer fibres for textile and other applications.” *Advances in Textile Biotechnology* 77-97. https://doi.org/10.1533/9780857090232.2.77.

Sinha, V, Patel, MR, and Patel, JV. 2010. “Pet Waste Management by Chemical Recycling: A Review.” *Journal of Polymers and the Environment* 18: 8-25.

Smith, L. 2022. “The nexus between climate change and healthcare.” *The Health Policy Partnership.* Accessed May 20, 2023. https://www.healthpolicypartnership.com/the-nexus-between-climatechange-and-healthcare/.

Steinmueller, W. E. 2001. “ICTs and the possibilities for leapfrogging by developing countries.” *International Labour Review* 140 (2): 193-210.

Strauv, E.T. 2009. “Understanding technology adoption: Theory and future directions for informal learning.” *Review of Educational Research 9* (2): 625-649.

Takeoka, Y. 2014. “Poly(vinyl chloride) (PVC).” *Encyclopedia of Polymeric Nanomaterials:* 1-3. https://doi.org/10.1007/978-3-642-36199-9_247-1.

Tomson, C. 2015. “Reducing the carbon footprint of hospital/based care.” *Future Hosp* J. 2 (1): 57-62.

United Nations Conference on Trade and Development. “Circular Economy.” Accessed May 20, 2023. https://unctad.org/topic/trade-and-environment/circular-economy

United Nations Environment Programme. 2022. “Eco-labeling.” Accessed May 20, 2023. https://www.unep.org/explore-topics/resource-efficiency/what-we-do/responsible-industry/eco-labelling.

United Nations Environment Programme. 2022. ‘’How can a life-cycle approach curb the plastic pollution crisis?’’ Accessed May 20, 2023. https://www.unep.org/news-and-stories/story/how-can-life-cycle-approach-curb-plastic-pollution-crisis.

United Nations Industrial Development Organization. "Circular Economy." Accessed May 20, 2023. https://www.unido.org/sites/default/files/201707/Circular_Economy_UNIDO_0.pdf

United States Energy Information Administration. 2023. "Consumption and Efficiency." Accessed May 20, 2023. https://www.eia.gov/consumption/commercial/reports/2007/xls/hospital/ H8%20Water%20Consumption_v4.xls.

United States Environmental Protection Agency. 2022. "Introduction to Ecolabels and Standards for Greener Products." Accessed May 20, 2023. https://www.epa.gov/greenerproducts/introduction-ecolabels-and-standards-greener-products.

United States Environmental Protection Agency. 2023. "What is a Circular Economy?" Accessed May 20, 2023. https://www.epa.gov/circulareconomy/what-circular-economy.

Wagner, M., Scherer, C., Alvarez-Munoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., et. al. 2014. Microplastics in freshwater ecosystems: what we know and what we need to know. *Environ. Sci. Eur.* 26 (1): 12.

World Health Organization. 2005. "Preparation of national healthcare waste management plans in sub- saharan countries: Guidance manual." Accessed May 20, 2023. https://www.who.int/water_sanitationhealth/publications/healthcare-waste-guidance-manual/en/.

World Health Organization. 2018. "Health care- waste." Accessed May 20, 2023. https://www.who.int/newsroom/fact-sheets/detail/health-care-waste.

World Health Organization. 2018. "The Philippines health system review: Health systems in transition." Accessed May 20, 2023. http://apps.searo.who.int/PDS_DOCS/B5438.pdf.

World Health Organization and UNICEF. 2022. "WHO / UNICEF Water and Sanitation for Health Facility Improvement Tool (WASH FIT) 2nd edition.'' Accessed May 20, 2023. https://www.unicef.org/media/119321/file/UNICEF_WHO_WASHFIT Second Edition.pdf.

World Wide Fund for Nature. 2021. "The lifecycle of plastics." Accessed May 20, 2023. https://www.wwf.org.au/news/blogs/the-lifecycle-of-plastics.

Appendix A. Project Timeline of Activities (Gantt Chart)

Activity/Output	Nov	Dec				Jan				Feb				Mar				Apr				May				Jun
	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
Initial proposal presentation	■																									
Submission of initial draft proposal	■																									
Consultation with thesis adviser		■		■																						
Revision of draft proposal		■	■																							
Submission of proposal plan and justification to CEU			■																							
Submission of feasibility report to UoM			■																							
Finalization of first draft proposal				■	■	■																				
Development of Plastic Waste and Sustainability Assessment Tool for hospitals				■	■	■	■	■	■	■	■	■														
Preparation of communication requests for hospitals and hospital directory/contact database												■	■													
Consultation with thesis adviser												■	■	■				■	■			■	■		■	■
Revision of assessment tool and translation into an online format													■	■	■	■										
Deployment of assessment tool to hospitals																	■	■	■							
Proposal writing																		■	■	■	■	■	■	■	■	
Follow- up of request to hospitals																				■	■					
Data collection and analyses ▪ Circular economy practices reporting ▪ Assessment of Waste Hierarchy Level ▪ Assessment of Technology Readiness Level ▪ Development of the Waste Hierarchy- Technology Readiness Level chart																					■	■	■	■		
Presentation of results and consultation with thesis adviser																							■	■	■	
Submission of the draft final report																								■	■	
Consultation with thesis adviser																								■	■	
Revision of the draft final report																										■
Finalization of thesis report																										■