Waste in humanitarian Operations:
Reduction and Minimisation

D4.2. Plug and play framework (policy brief)

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LIST OF ACRONYMS

ACRONYM	FULL NAME
BPs	Bio-Plastics
EC	European Commission
EMCA	Environmental Management and Coordination Act
FRC	Finnish Red Cross
HO	Humanitarian Organization
ICRC	International Committee of the Red Cross
MCDA	Multi Criteria Decision Analysis
MoH	Ministry of Health
MONRE	Ministry of Natural Resources and Environment
NEMA	National Environment Management Authority

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NRC	Norwegian Refugee Council
VNRC	Vietnam Red Cross Society
WHO	World Health Organization
WM	Waste Management
WP	Work Package

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BACKGROUND ABOUT THE WORM PROJECT

WORM aims to design guidelines and support actions for circular economy in the humanitarian sector. It integrates bio-based technological solutions, leverages procurement for waste reduction, improves waste management methods and prioritises the sustainable livelihoods of waste pickers. WORM focuses on two selected settings: field hospital deployments and humanitarian livelihood programmes with a waste picking component. Following a collaborative and multi-actor approach, WORM brings together medical and humanitarian organisations, procurement service providers, logistics providers, waste management services and academic partners.

EXECUTIVE SUMMARY

This document is a deliverable of the WORM Project, funded under the European Union's Horizon Europe research and innovation programme under the grant agreement No 101135392.

The aim of this document is to demonstrate the plug and play framework suitability for the application at the field hospital for waste management to bridge the gap between HOs and local waste service providers with regard to selection of waste treatment technology and the coupling of the waste management process in the reality.

The deliverable describes the available medical waste treatment technology and the current application of different technologies at the hospitals around the world, including the tool used to guide the selection of the suitable technology. Multi Criteria Decision Analysis (MCDA) framework was developed from theoretical standpoint of decision making in multicriteria settings. The criteria setting was critical for the establishment of the framework as it will construct a view of the importance of each factor in the decision process. Review on the criteria settings for the medical waste treatment process together with the responses from interviews, survey showed the necessity to include the element on the operability of the treatment technology under the context of humanitarian setting.

A decision tree and MCDA framework have been constructed for online platform to interact and collect feedbacks from stakeholders. The assessment using MCDA framework recommended the extensive collection of preference in criteria settings and the importance of each criterion with different humanitarian organizations (HOs) and waste management (WM) service providers to be able to inform reliable WM technology selection. Initially, recommendations from participants show higher importance of the operability under the humanitarian context for the selection of waste treatment technology. Meanwhile, there exists a gap in understanding between HOs and local service providers in both the technology offered and the reliability of services, thus a recommendation on the certification program or database of the certification can help with guiding suitable service providers for field hospital deployment wishing to integrate with local waste service. The findings also show a need for a better alignment between the procurement process and guideline with the appropriate medical waste treatment technology selection. Because, there is a current gap between the available medical waste treatment technology concerning the biobased and biosourced materials which has been initiated at the procurement stage.

NON-TECHNICAL SUMMARY

This document describes the current availability of medical waste treatment technologies and introduces a framework to support the integration of local waste management services with the HO operations deploying field hospitals to meet the requirements set by HOs and local regulation while ensuring the sustainability of operations and protecting the environmental and the wellbeing of local residents.

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1.1. Waste Management in Field Hospitals Settings

Context

Waste generated during field hospital deployment is influenced by many factors, ranging from internal practice to the external requirements of the host country or region. Deploying a field hospital is a highly complex process that requires strong coordination from suppliers (providers of necessities and equipment) and a thorough understanding of the local context. The local context significantly impacts the deployment, and the management of waste generated during the operation treated. Filed hospitals are often set up near conflict or disaster-affected areas, where the basic infrastructure is limited, and waste management infrastructure is either damaged or nonexistent.

Field hospital deployment adopt various approaches waste treatment ranging from self-contained treatment facilities included in the hospital set up to contracting third-party waste management services. Establishing connection with local waste management providers offers flexibility, as it eliminates the need for costly, standardized treatment systems that require technical operation. Partnering with and supporting local suppliers can make deployments more sustainable and facilitate compliance with local regulatory framework. However, the responsibility for ensuring the proper treatment of waste-particularly medical and hazardous waste-ultimately remains with the HMO deploying the field hospital.

To better understand the local context of the HO waste management-specifically regarding the availability of waste treatment technologies, regulations, and options for integrating local waste providers with field hospital operations- WP4 members conducted an extensive analysis. This included a literature review of available medical waste treatment technologies and a survey of stakeholders from different regions and countries, including waste treatment providers, hospitals, international HOs, and government agencies. Interviews were primarily conducted with HOs involved in field hospital deployment and management (International Medical Corps - IMC, Norwegian Refugee Council - NRC, Finnish Red Cross - FRC, Vietnam Red Cross Society - VNRC). Additionally, surveys and a “plug and play” exercise were conducted with both HOs and local waste management service providers (n=21). The analysis was followed by another survey round to assess the applicability of technologies to the field hospital settings to evaluate criteria for selecting local waste management providers.

Waste composition differences

Reports on the composition of waste generated by field hospital worldwide indicate that 75% - 90% of the waste produced is comparable to domestic waste and usually classified as “non-hazardous” or “general waste” (Chartier 2014). This general waste originates from administrative, kitchen, and housekeeping area and includes materials such as organic waste and packaging. The remaining 10–25% of health-care waste generated in hospitals or other medical settings is considered as “hazardous” and poses a various environmental and health risks.

The WORM survey revealed that a majority of respondents (50%) reported dealing primarily with non-medical waste while about 25% reported managing medical waste at their deployment sites. Additionally, approximately 20% indicated they handled a mixture of non-food and medical waste. This suggests that in some deployments, the treatment process involves combined methods such as incineration for both non-food and medical waste.

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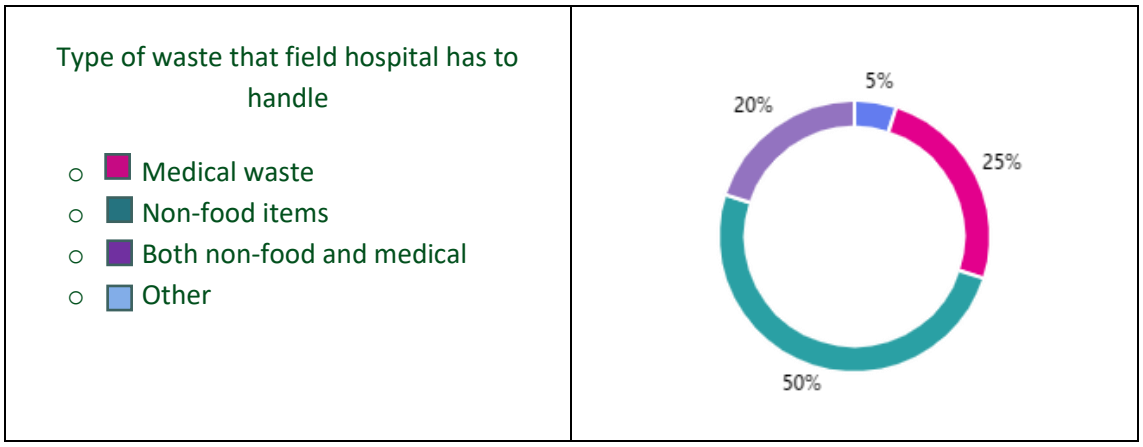

Figure 1: Waste generation at field hospital

Waste management facilities and connection with local waste management providers

The waste management practices in field hospital settings are highly dynamic and depend on various factors, such as the type of waste to be treated (e.g, general waste from administrative activities or hazardous and infectious medical waste) and the availability of suitable waste treatment technologies. Consequently, multiple approaches to waste management practices must be considered. In ideal situations, where reliable and well reliable and well-developed civil waste management infrastructure exists, field hospitals can contract local waste management services. This approach reduces the burden on HOs, eliminating the need to design and transport their own waste management facilities. However, in many cases, field hospitals are deployed in locations lacking basic infrastructure, including adequate waste management systems. In such scenarios, HOs must prepare their own waste management services, often designing and transporting facilities to be set up within the compound.

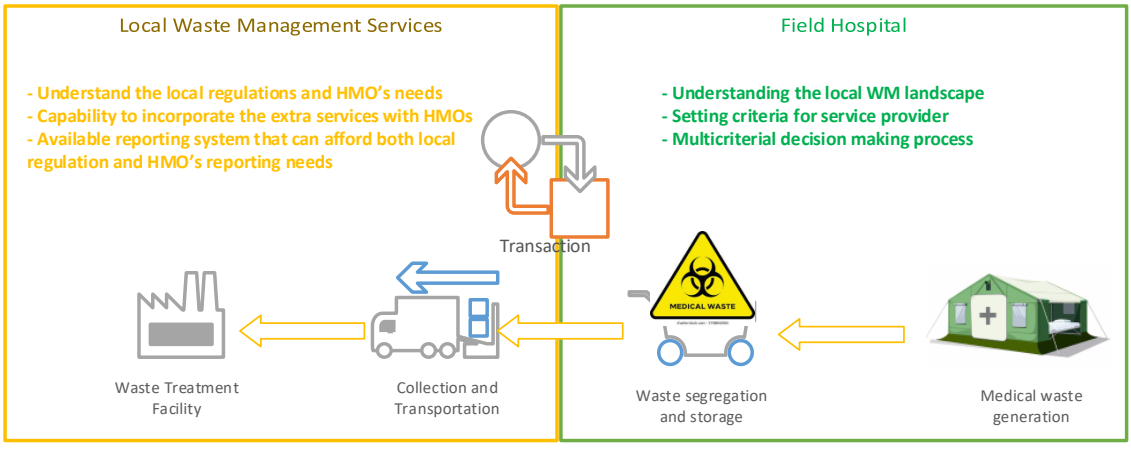

Figure 2: The considerations from both sides (HOs that operate field hospital and local waste service providers)

However, even in the case the HOs are ready to deploy its own waste treatment facility, it is still worth considering if any part of the waste management practices can be coupled with the local waste management service providers. According to the guideline developed by ICRC (ICRC), then in certain circumstances the subcontracting with the service provider for transport/treatment/disposal happened by requesting services from private companies of any cooperation of the health-care facilities in the region that the deployment happening. In that case, it is better for the overall environmental and economic benefits because of the management scale as well as the opportunities to utilize the recycling process at

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place to minimize the waste impact on environment footprint. The survey result with HOs shows that there are diverse options of collaboration between field hospital and local waste service providers, in which about 37% respondent agreed with the service-based contract. The type of contract suggested that some form of local waste treatment facility has been integrated with the operation of the field hospital. The remaining answers are for other types of collaboration (mostly on partnership and others model implying that HOs treat the waste generated by themselves).

Figure 3: Involvement of local waste management in the treatment of medical waste

Available medical waste treatment technology (focus on field hospital)

The current available and proven medical waste treatment technologies are well-documented in the literature and guideline from WHO and HO operation, they are currently widely used both in the context of regular healthcare facilities, centralized medical waste treatment facilities and mobile units. Studies have shown that about 49–60% of healthcare waste has been treated by incineration technology, while 20–37% gone through autoclaved, and 4–5% was disposed of using other technologies (Attrah, Elmanadely et al. 2022). The treatment technologies can be broadly characterized into destructive and non-destructive treatment technologies. The most popular medical waste treatment technology is destructive-based pyrolysis and incineration processes while the non-destructive treatment technology included autoclaving, hydroclaving (Maamari, Mouaffak et al. 2016), microwaving and other emerging technologies.

Destructive treatment measures such as incineration has seen more applications both in term of fixed and temporary installation conditions due to its ease of adoption. There are reports and documentation of variations of the incineration technology (especially the small-scale and mobile unit) that do not meet the emission standards (Batterman, Water et al. 2004). Because of the potential of toxic emission of dioxins (Prathish 2023), furans (Alvim Ferraz and Afonso 2003) and heavy metals from incineration processes, new treatment techniques such as microwaving and autoclaving have been adopted as alternative treatment methods to incineration (Windfeld and Brooks 2015). The original driving for alternative treatment technology to the incineration is due to the environmental impact of the contaminated air and energy use, in addition to that primary cause the other motivation is the current demand on the circular economy practice in waste sector in general and in medical waste in particular. Thus, alternative measure such as autoclave (and other non-destructive treatments) of infectious medical waste has been considered more environmentally advantageous.

In prior applications, autoclaving has been combined with landfill treatment to both reduce cost and environmental impact. However, with additional consideration on the circularity of the material, the treatment technology has been evolved to include the plastic recycling in between the autoclaving and

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landfill treatment process. Compared to destructive treatment of incineration, the non-destructive treatment technology can facilitate material recovery (such as plastics) while limiting the adverse environmental and public health impacts resulting from improper incineration operation (Lee, Ellenbecker et al. 2004). In both destructive and non-destructive waste treatment technologies, there are different variations in the combination processes to recover materials and energy such as combined steam sterilization + landfill, microwave disinfection + landfill, or pyrolysis + gasification (Emmanuel, Puccia et al. 2001).

There are also emerging technologies for medical waste treatment such as gas phase chemical reduction, base-catalysed decomposition, supercritical water oxidation, sodium reduction, vitrification, superheated steam reforming, sonic technology, electrochemical technologies ozonation, plasma gasification/melting, sulfonation nonetheless, these emerging technologies are not ready for routine application to health-care waste (Giakoumakis, Politi et al. 2021).

Survey carried by WORM/RMIT with HOs and waste management companies in low-income and middle-income countries showed that majority of companies currently use incineration as the main medical waste treatment technology. The application of on-site and off-site autoclaving is the second most popular treatment. The autoclaving treatment often goes in tandem with landfill treatment thus we also see similar proportion of landfill treatment technology.

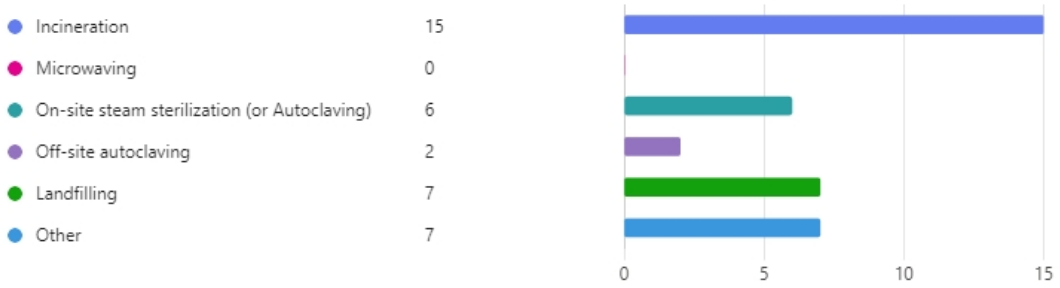

Figure 4: Treatment technologies used for medical waste at field hospital (including that used by local waste treatment provider)

Relevant regulations and guidelines with medical waste management across case study areas

Some of the relevant international guidelines on medical waste management include

- The handbook of Safe management of wastes from health-care activities published by WHO in 2014 (Chartier 2014)
- Technical Guidelines on the Environmentally Sound Management of Biomedical and Healthcare Wastes (Convention 2003)
- Article 5 Stockholm Convention on Persistent Organic Pollutants on the reduce releases of POPs from unintended production where Medical Waste Incinerators have “the potential for comparatively high formation and release” of dioxins & furans and the priority consideration should be given to alternative technologies that avoid formation of dioxins & furans (Guidelines on Best Available Techniques and Provisional Guidance on Best Environmental Practices Relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants, Geneva, December 2006) (Fiedler 2008).

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Finland related regulations

Medical waste management in Finland is governed by both national (Waste Act 646/2011, Decree on Waste 179/2012, Health Protection Act 763/1994) and EU (WFD 2008/98/EC, Regulation of Shipment of Waste 1013/2006) regulations, ensuring that waste is handled, transported, treated, and disposed of in a way that minimizes health risks and environmental impact. Principle approach for medical waste handling is that waste must be treated to neutralize any infectious agents and reduce its hazardous properties before final disposal. Common medical waste treatment methods include incineration and autoclaving. Landfilling is generally avoided unless the waste has been rendered non-hazardous.

Vietnam related regulations

To ensure the safe handling of healthcare waste, the government has established various legal frameworks, including laws, policies, and standards, to guide and support its management (Dang et al., 2021). The regulations encompass various aspects, including the classification, collection, storage, transportation, and treatment of medical waste. These regulations are primarily governed by the Ministry of Health (MoH) and the Ministry of Natural Resources and Environment (MONRE), with specific responsibilities assigned to different agencies and organizations.

Vietnamese guidelines and regulations for medical waste management have been quite structured from the source separation, transportation, treatment and circularity element. In which there has been dedicated guideline for source separation concerning the medical premises and the licensing of organizations with proper medical waste handling and treatment technologies. Notably, the government has issued specific guideline for the circularity application in the medical waste handing process (with example of current business employing circularity in medical waste treatment process in Vietnam, documented in this report and D 3.1). Additionally, the regulation also details the specific medical waste treatment types for hospitals, cluster of hospitals or clinics and other types of treatment acceptable in the challenging conditions involving on-site treatment which is applicable to the disaster relief and field hospital settings. More information to Vietnam related environmental protection related to medical waste is included in Annex 1.

Kenya related regulations

The Kenyan guidelines for medical waste management are implemented and enforced by various important regulatory bodies. The MOH is the major agency in charge of this, as it establishes the general guidelines and rules pertaining to the management of medical waste. To ensure that the established guidelines and standards are followed and implemented at the local level, the MOH collaborates with other agencies including, the National Environment Management Authority (NEMA) and the county level-local government. Regulations governing medical; waste management in Kenya are designed to prevent environmental contamination. The following are main legislations and guidelines regulating medical waste management in Kenya. The nation also issued the Guidelines for Safe Management of Health Care Waste (2nd Edition, March 2024), which presents an update to the current management of hazards and risks related to healthcare waste handling and incorporates the management of chemicals and POPs. More information to Kenya related environmental protection related to medical waste is included in Annex 2.

Consideration for material recycle and bio-based materials in the medical waste treatment

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Concerns about the increasing carbon footprint, air pollution during the phase of treatment for the fossil-based plastic have prompted the society and industry to develop and adopt biosources and bio-based plastics for various uses. Based on their diverse types, Bio-Plastics (BPs) and biopolymers are divided into biodegradable and non-biodegradable BPs (Kabir, Kaur et al. 2020). Biopolymers and BPs that are not biodegradable are anticipated to be the most popular and fastest growing for consumer products. Biodegradable plastics are gaining acceptability in household usage, packaging industries nevertheless, they occupy a rather small section of the plastic market (Rai, Mehrotra et al. 2021). The healthcare sector has recently begun to consider bioplastics in its applications such as personal protective equipment, food-service ware, and packaging however the adoption and the market share is still very small in the medical supply chain.

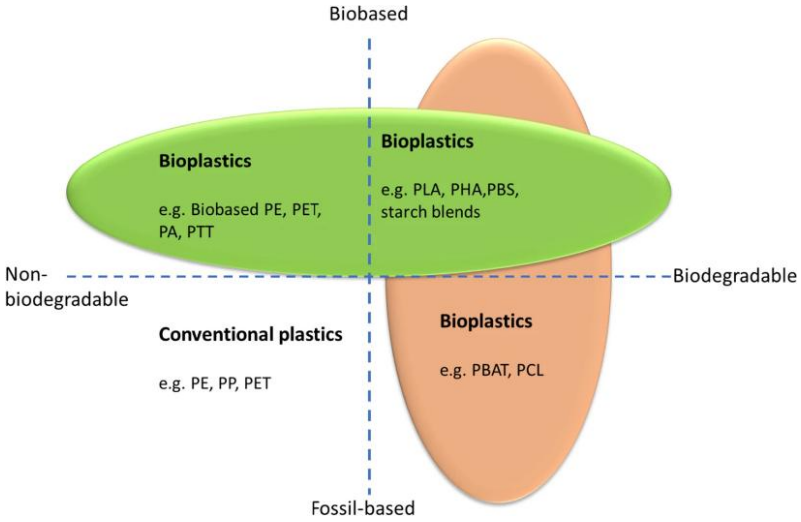

Figure 5: Classification of materials according to biodegradability and bio-based composition. Adapted from (Ahmad, Banat et al. 2024).

There has not been much guideline for the treatment of the bio-based materials in the medical waste treatment stream. Based on the characteristics of the Bio-Plastics (BPs) materials, other than conventional incineration, the composability or recycling of the biopolymer has been discussed as a means to achieve environmentally friendly disposal of the materials after use for medical purpose, with proper disinfection (Kyrikou and Briassoulis 2007, Joseph, Unni et al. 2023). However, there are still issues have to addressed for the bioplastics treatment in general purpose as well as in medical waste context such as the rate of bioplastics decomposition (or compostability) (Kawashima, Yagi et al. 2019) as well as the potential for recovery of the materials in the bioplastics (requirement of materials that can withstand multiple sterilization cycles without degrading) (Moshkbid, Cree et al. 2024).

There are still debates on the environmental sustainability performance of the current bioplastics in the market (Yu, Diamond et al. 2024). Because most commercially available bio-polymers or bio-based materials that are marketed as compostable require treatment conditions only available in specific industrial composting facilities (Lambert and Wagner 2017). Therefore, at the current stage, there has not been much application of the special treatment methods for the bio-based plastic in non-industrial context. Both biodegradable or compostable plastics currently have not been recognized or included in the conventional recycling and organics waste streams, and they are still considered as contaminants to the existing treatment method. In light of that, most of the variations in the treatment process for medical waste were surrounded the mutation of (autoclaving + microwaving) + incineration (plus for heat recovery)/pyrolysis + landfilling options (Hong, Zhan et al. 2018, Zhao, Wang et al. 2021) in which biobased and biosourced materials have not been considered. Thus, if adopted by healthcare organizations,

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bioplastic waste would cause major disruption in the existing recycling and composting programs (Yu, Diamond et al. 2024).

The survey of local waste management service providers and the HOs showed that most of the recycling practice are done with the packaging materials. Respondents also reflected that the country is currently not benefit from the recycling, repurposing of materials from medical waste stream (Annex 3). Most of the notable recycling activities has been done with the non-hazardous materials from hospital or field hospital (bottle, wood, non-hazardous plastic). While there are some relevant recycling activities to the nonmedical waste, the practice of sterilizing (through autoclaving) of medical waste then recycling plastics in the stream before further landfill treatment has not been observed in Kenya except a case in Vietnam (interview with stakeholder from medical waste treatment sector of Vietnam). The applicability of the process signifies the possibility of the circularity application for the waste stream from hospital and field hospital (see figure 4). The practice is also similar to the current hospital waste treatment in China, Korea and other (Zhao, Wang et al. 2021). This is conditional on the availability of the service as well as the guarantee of all the process from transportation to the disposal that can meet the requirements of local regulations as well as HOs. Thus, the section of selection criteria of the service provider will further consider this element for the construction of plug and play framework.

Figure 6: Comments on the circularity and biobased materials in the field hospital waste

Concerning the application and adoption of bio-based materials, there were not many options available in terms of alternative medical products and competitive price that can be widely scale up in the field hospital. Reports and publications mentioned about the available of bioplastic alternative such as masks, gloves, bandages (Yu, Diamond et al. 2024). However, results from our survey and interviews with stakeholders showed that there has not much progress in utilizing these new alternatives in the humanitarian sector. Typical answers are “We keep eyes open for biodegradable products” and “Currently sourcing best system to adopt”. This signifies that the ecosystem for the bio-based and bio-sourced plastics even though have established somehow has not been integrated with humanitarian sector from the procurement to the disposal stage. It is either because the treatment and reuse of the bio-based, bio-sourced alternative has not been matured enough to offer a reliable disposal, or the adoption of that in the procurement and supply chain is limited to start a meaningful exploration of suitable recycling and treatment technologies of the waste stream containing bio-based and bio-sourced materials.

1.2. Decision related to WM at field hospitals

Humanitarian organizations have developed waste management reference (ICRC) for field hospital deployments or utilize the guidebook developed by WHO (Chartier 2014). There are many variations to the options that can be made for the waste management program to be considered. The process involved with several internal and external interactions, while ensuring internal protocol (on procurement, safety procedures…) it also has to pay attention to the external requirements from the local authorities, the availability of the local services. Especially in the context of waste minimization, reduction of

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environmental impacts, material circularity and the new materials in the waste stream, thus the decision-making process in selection of technologies, suitable service providers are multicriteria in nature. In that process, the decision-making process needs to clearly identify its goals, criteria and a process to arrive at the best available options.

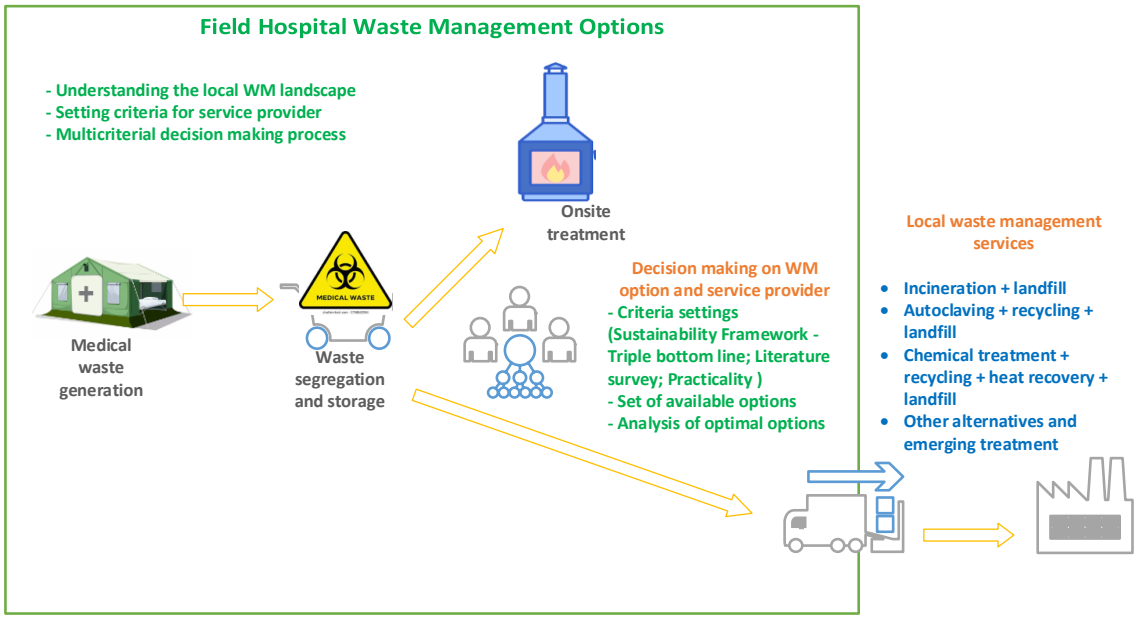

Figure 7: Field hospital waste management options

1.2.1 Decision tree

The decision tree for field hospital waste management was constructed and tested with different questions and hypotheses developed from the interview and survey with stakeholders. In addition to the information gathered in the survey and interview, the literature review also helped guiding the current literature and research in the waste management practices. In the current reference of ICRC (ICRC), the decision support with medical waste management has been formulated in the form of checklist for the required activities and actions for the waste management process. In view of the current advance in the decision-making assessment tools, more information is available to guide the selection of service providers as well as technologies for the waste stream generated in a systematic manner. Studies have utilized the decision tree in application for the medical waste management at the clinics (Pillay, Hansraj et al. 2024) as well as to guide the investment alternatives for medical waste management (collection, transport, disposal) or consideration for sustainable waste management (new eco-incinerator, sustainable landfill, etc) (Csorba and Crăciun 2018). Therefore, arriving at the decision tree allows the assessment and comparison of the potential alternatives for strategic decision that meet the certain criteria set out by the organization, the industry and community of practitioners.

The goal of the decision tree and its decision support are to guide the selection of suitable treatment technologies meeting the requirements of the HOs as well as reflecting the context of the field hospital settings. In which there are several factors concerning the field hospital settings such as short-term (rapid respond deployment), extended term (long-term deployment either within a camp or standalone), network of deployment, or embedded in the local infrastructure or medical clinics supporting disaster relief responses. In this study, the decision is to support the selection of the suitable treatment technologies towards non-destructive treatment if possible while maintaining the criteria of the HOs and the local regulation. In meeting the local regulation, if there is a local service provider, it is always preferable to establish the partnership. If there are several local waste providers with different

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technologies, then the decision support will guide the selection of the most suitable technology according to the criteria and the established threshold (threshold assessed through survey with stakeholders). If there is none suitable local service provider, then the selection of on-site waste treatment will be guided.

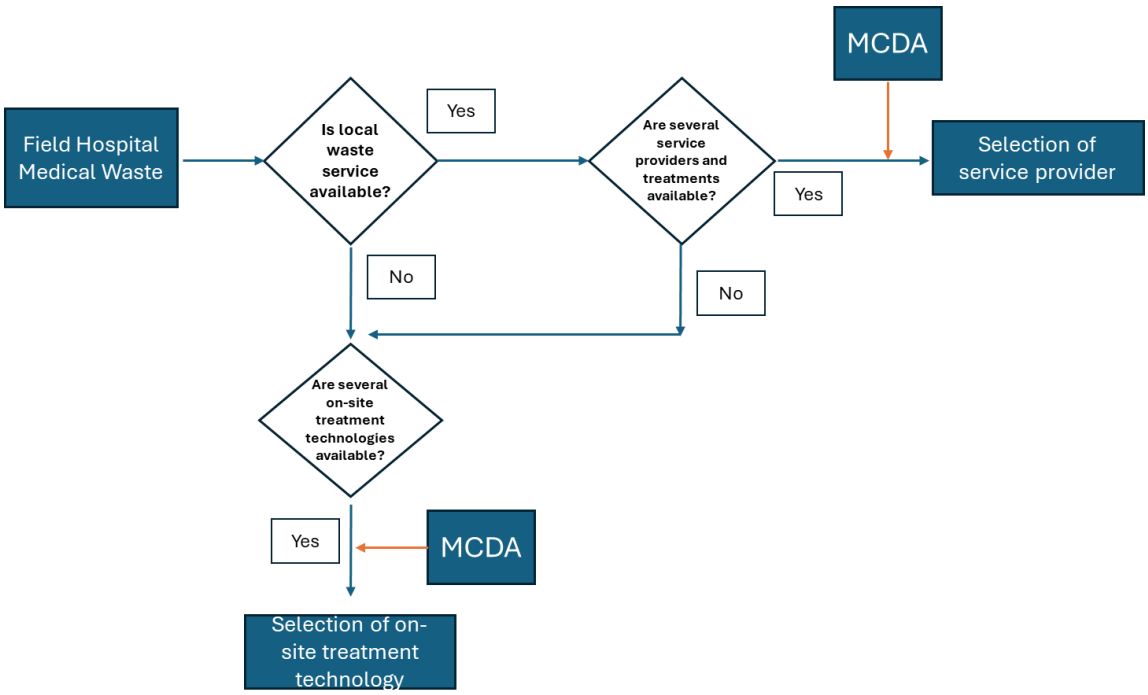

Figure 8: General decision tree for medical waste treatment and the assistance of MCDA assessment at the field hospital

1.2.2 Multi Criteria Decision Analysis (MCDA)

Medical waste treatment in normal context involves complex process consisting of waste collection, transfer routes, disposal plant location, treatment technology selection, and any possibility of material or energy recovery. The medical waste treatment in the field hospital is even more complex as the local conditions regarding the waste management, infrastructure mostly unknown or less certain. Thus, there are few steps in the selection of treatment alternatives in which multi-criteria decision making (MCDM) tool can be of a great help such as the selection of suitable local service providers or in case there is no service provider is the selection of appropriate on-site treatment technologies.

The MCDA technique has been widely used in evaluation process for various sectors concerning the decision between different alternatives with a set of criteria and scoring system. In the MCDA technique, different measurement variable and metrics can be incorporated to construct the indices guiding the selection. Similarly, the planning and implementation of the field hospitals by HOs also face with the decision constrained by criteria that HOs want to achieve. Thus, an established evaluation framework that supports the ranking and guiding of suitable options at different context and criteria is desirable and necessary.

MCDA nowadays has a large number of refined methods. The use of multicriteria analysis in waste management possesses the advantage of rendering subjective and implicit decision making more objective and transparent. In a nutshell, the MCDA methodology involves four distinct steps to address the nonlinearity of the decision-making process including the structuring of the decision-making issue; formulating the criteria, preferences system and modelling the preferences; aggregating the alternative evaluation and finally making recommendations (Guitouni and Martel 1998). The major characteristics

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shared by all MCDA approaches is their focus on the evaluation and addressing the ranking or sorting alternatives. This form of evaluation is of major interest to the decision-making context as it involves the expression of the preference that every real-world decision-making process faced.

MCDA methodology has been applied in many situations and contexts facing medical waste treatment such as the selection of the most suitable healthcare waste incineration using the extended sustainability criteria setting (Puška, Stević et al. 2022). Other studies and application applied MCDA to analyse the overall process of medical waste management system (consider all phases of the medical waste management) (Aung, Luan et al. 2019). MCDA was also utilized to assess the comparative performance between distributed incinerators and centralized autoclave, hydroclave options in Greece to show that centralized autoclave does outperform other incineration treatment (Karagiannidis, Papageorgiou et al. 2010).

The MCDA used for the field hospital medical waste management followed the traditional framework which set out with the survey for criteria suitable for the HOs and the waste management agencies. The further assessment of MCDA based on criteria and the scoring system to aggregate the priorities for certain treatment technologies available for the medical waste in the settings of the countries and organizations. The criteria settings and further assessment with the threshold of different criteria where the respondents see it is satisfactory with the recommended treatment technologies was collected through second round of plug and play to fine tune the guidance. The MCDA framework was further built with the small database of the relevance regulation guide and service providers that can provide the service to assist the coupling of the field hospital waste management with local service provider.

Moreover, as studies have shown, the performance of different medical waste treatment alternatives is strongly dependent on the selection and weighting of criteria, which is varied significantly and sometimes is neglected by the administrators and decision maker (Ishtiaq, Khan et al. 2018, Puška, Stević et al. 2022). In addition, since the criteria setting in the MCDA will be mostly based on the review, on certain guideline and orientation such as the sustainability triple bottom line principles, extended sustainability framework or additional practical framework for certain field, thus the criteria setting will guide the MCDA selection and recommendation process.

1.2.3 Criteria settings

As mentioned about the importance of criteria setting in the MCDA methodology. Traditional framework for sustainable development studies using MCDA utilized the sustainability triple bottom line criteria (3P = Profit, People, Planet). Depending on the need of understanding in any context, additional criteria will be added to reveal the difference perception and preferences in decision making processes. In the context of HO operation and the needs for waste minimization and the circular economy, studies have adopted the recycling criteria in the framework for assessment of medical waste management providers for hospitals in Pakistan (Ishtiaq, Khan et al. 2018). The extended sustainability criteria have been developed and used differently by researchers where they adopted additional dimension out of the 3P criteria in traditional framework. The additional dimension in the extended sustainability framework includes technical criteria of treatment devices (Puška, Stević et al. 2022), or acceptance and ease of operation (Karagiannidis, Papageorgiou et al. 2010). Other studies deepen the assessment and understanding in adding more details to the treatment devices criteria such as the treatment reliability and treatment effectiveness as sub-criteria in their MCDA analysis (Shi, Liu et al. 2017).

Survey have been conducted with HOs and waste management companies relevant to the medical settings to understand about the decision regarding the selection of medical waste treatment practice at field hospital. At the same time, the survey also tried to quantitatively represent the different perception

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and preference in waste treatment technologies. As mentioned earlier, one of the aspects of the MCDA the incorporation of perception and affinity in the aggregated of scoring to reflect the preference with different choice. In the medical waste management guideline developed by ICRC, the checklist for describing the current situation have not mentioning on any criteria if there is more than one waste services or waste treatment technologies are available. In addition, the check list did not have any recommendation regarding the treatment technologies enabling the circular practice, recycling or environmental footprint for the onsite medical waste treatment or local service provider.

Table 1: Result of survey on the criteria that HOs and waste management services considered important for medical waste treatment selection

Criteria for selection of medical waste treatment technology	Scoring (%)	Standard deviation (%)
Economic efficiency	13.5	5.7
Environmental footprint	14.6	3.4
Wellbeing of employee and citizen	15.4	5
Operability under humanitarian context	19	10.4
Ease of adoption in terms of local protocol, policy, and regulation	14.3	4.3
Capacity to adopt bio-based and biodegradable materials	11.1	5
Capacity to adopt circularity practices	12.1	3.7

The answer on the criteria of the HOs and waste management organization to choose medical treatment technologies shows that the criteria on the operability under humanitarian context was rated highest. Which is understandable as it is the highest operation performance that HOs and waste management organization considered for field hospital. While the second highest was placed on the wellbeing of the citizen and employee which is about the safety and the wellbeing of the surrounding communities. It is also the priority for HOs operation as to save life and ensure the quality of life for the surrounding environment.

It is noteworthy that the criteria regarding the adoption of bio-based and biodegradable materials and circularity in the medical waste treatment technology was rated the lowest. It is mostly due to the fact that the bio-based and biodegradable materials do not currently exist in the waste stream, this is further supported by the answer from qualitative interview (annex 3). Thus, not much attention has been paid for its treatment. At the same time, as previously reviewed, the treatment technologies for bio-based and biodegradable materials in medical waste is just at the initial stage and very rarely existed within the normal context of hospital waste, and hence mostly nonapplicable in the field hospital setting.

In this exercise with HOs and waste management agencies for the selection of waste treatment technology, we keep the same criteria as surveyed to start with the MCDA methodology. This is to emphasize the connectivity between the procurement of the biobased and biodegradable materials with selection of suitable waste treatment technologies to render the intended environmental and social

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benefits of new biobased materials in the humanitarian supply chain. For the current practical application of the MCDA, a combination of the exploratory understanding of the biobased materials and the circularity status criteria can be combined.

Lastly, as the qualitative interview also reveal, in certain context the HOs tend to use only one criterion such as the "operability under humanitarian context" there are both lack of guideline on the selection of competing alternatives and the lack of quantitative measures to compare and guide in the MCDA process. It is also noted that sometime the HOs also prefer to take care of its own medical waste treatment by deploying the incinerator together with the field hospital to minimize the risk of unsafe disposal of medical waste by local service provider. However, in overall consideration, since the goal of HOs deployment is to save lives and protect the surrounding living conditions and maintain the operational sustainability, the coupling of the medical waste treatment with local service providers would render much needed social and environmental benefits that the MCDA can be of useful assistance.

1.3. Plug and play framework with local WM partners (field hospital)

Plug and play framework has been designed and tested with WM partners following the described methodology of criteria setting and MCDA for field hospital medical waste management. The framework following three different steps with the first step is the setting of the initial condition (on the type of waste stream, the country of operation and the type of deployment). The second step is the rating of the criteria which has been selected based on the first phase of interview and survey with respondent as listed in Table 1. After the selection of different criteria and its scaling, based on the pre-defined aggregate method and decision tree of the waste treatment technology and the collected local regulation, policy for the specify waste stream, the system will show the recommended waste treatment technology available for the type of waste (in the phase the most data collected is related to medical waste). Additionally, the system also shows the available local waste treatment provider that offer the type of treatment technology recommended.

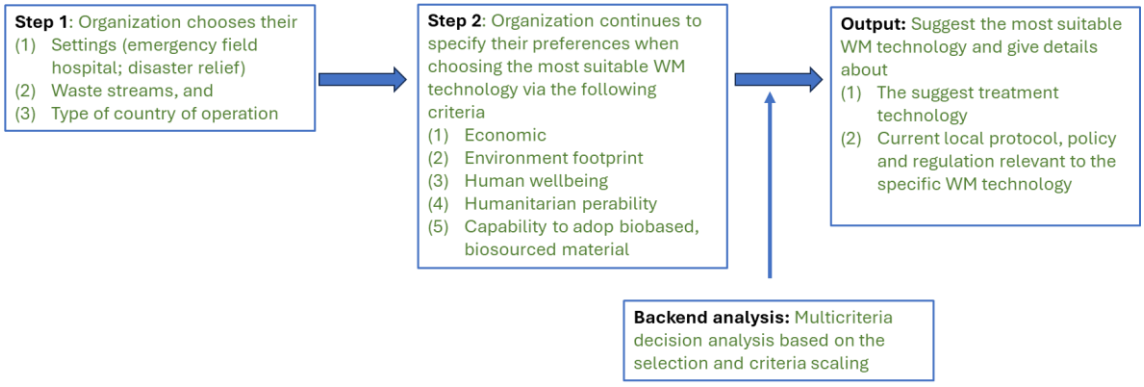

Figure 9: Flow chart of the plug and play framework.

The current decision tree and aggregation of scoring of MCDA rule for the recommendation of treatment technology based on the feedback of the users when playing with the MCDA rule based on the criteria setting range from 1 to 10 for each criterion. The result suggests the following categories:

1. **Incineration is always accepted when:**

- Users prioritize economic efficiency (high economic concern) and are less concerned with environmental footprint.
- Suggestion: If economic efficiency > 7/10 and environmental footprint < 5/10, Incineration is a good fit.

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- Anytime the economic criterion is set higher than environmental footprint criterion

2. Microwaving is only accepted when:

- User evenly care about the economic, environment and operation and reg between 4 and 6
- Microwaving seems not well received by most respondent

3. Landfilling is acceptable only when environmental footprint is not a priority:

- If environmental footprint criterion ≤ 5.5/10 then landfilling is the suitable option
- If environmental footprint criterion > 5.5/10 then Landfilling is rejected.
- Landfilling suggestion is acceptable only if environmental footprint < 6 and economic efficiency is medium (economic efficiency between 4/10 and 7/10).

4. Autoclaving is recommended when a good mix of economic, environment:

- Autoclaving is the secondary option for balanced scenarios if environmental footprint > 6/10 and economic efficiency is between 4/10 and 6/10.

After the aggregation of the criteria scoring and the decision tree logic in the WM technology guidance, following the general process of MCDA, there must be an assignment of priority scoring (giving weight to the score). It can be done by another sampling with HOs and WM companies but can be combined with the step of defining the criteria in Table 1 where we can see a stratification of the percentage of respondents with each criterion. In this exercise, we are using even priority to all criterion for the final aggregation and guidance of WM technology. The final guidance of technology suitable for the field hospital medical waste treatment must be match with the availability of local waste management service. Currently there are only four different WM treatment technologies available in the library (sanitary landfill, incineration, autoclaving, and microwaving). The tools did not go further to recommend the combined treatment measures such as autoclaving + landfill with the assumption that if there is non-destructive waste management treatment recommended the final disposal of the waste after the non-destructive treatment is the landfill.

1.4. Recommendations

There is a gap in the coupling of HOs operation and WM with the local service providers. It is identified as the lack of understanding between the criteria setting of both sides where the HOs on one side have to comply with local regulation and thus a coupling with local service provider which can offer sound treatment method and technology is ideal. However, on the other side, they have concern on the uncertainty level of the treatment outside of their control because as regulation (in Vietnam and elsewhere) stipulates that the owner of the medical waste is responsible for the proper treatment of the waste. Therefore, until a certification process on the treatment's certainty and quality of the local management companies can be established, there is still reservation on the side of HOs to further delegate the waste treatment task to the local provider (Annex 4).

In the plug and play framework and the methodology for the multicriteria decision support, the critical step is the identification of suitable criteria that address the conditions of the decision context especially in the field hospital waste management. The concern that most of HOs and waste management companies raised was on the operability of the treatment technology under the situation of lacking connectivity in infrastructure as well as the lack of understanding on the requirements from both the HOs and the local service providers. Many of the considerations in the literature is about the extended sustainability criteria such as the treatment reliability and treatment effectiveness, however in this context of field operation, both the survey and the interview have shown a strong recommendation to include the operation under the humanitarian context as one of the key criteria in the MCDA in addition to the economic efficiency and environmental footprint. Future adoption of the framework can dig deeper in the operability dimension to include other sub-criteria to reflect the exact condition of the different treatment option such as the combination of autoclaving with landfill as opposed to only autoclaving in

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this exercise. By carrying this exercise, however, will help both the HOs and WM service providers to understand better their and their partner's priority areas to be able to couple the WM system together in the local context.

Thus, MCDA can be a starting point to collect the criteria and assessment of suitable technologies, service providers, it can also serve as the place to understand the local context and even the certificate or protocol that local service providers currently used (Annex 5) to inform the HOs for further the partnership. As noted in the analysis, the MCDA can ingest both the quantitative and the preference of the use through the setting of weights in each criterion. The more perception and users give their assessment in MCDA, the more accurate the tool can be able to recommend the right option for the decision-making process. This can be easily adopted in any field hospital deployment once the database of the local regulation, certificates and service providers updated and maintained. The guideline for the MCDA application in the field hospital setting waste management can be extended to include in the new reference for medical waste management as the maturity of the tool has been demonstrated both in literature and practice.

The bio-based bio-sourced materials consideration has been added into the survey and in the assessment framework. However, since there has not been a case of real application in the HOs and local context, thus their validity and relevancy to the assessment is limited. It is either that the technology is not available at the operational level and there has not been much demand for that type of materials in the medical waste sector. The future considerations for further development and identification of suitable technologies need to work closely with the procurement process to ensure that the treatment for biobased and biosourced materials can render the environmental benefits that those materials development and procurement are aimed for. In this exercise of WORM, the criteria for biobased and biosourced materials were implemented with weighting score equal to other criteria, however, it will be changed in different contexts and policy requirements (such as in Vietnam, it seems that regulation is currently geared to support the circularity and low environmental footprint, then that criteria for Vietnam can be higher than that of Kenya). There has been example of circularity in medical waste management from WM service provider in Vietnam.

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ANNEX SECTION

Annex 1: Vietnam related regulations on medical waste management and treatment

Below is a detailed overview of the regulatory landscape, categorized by legal authority and specific focus areas.

-Law on Environmental Protection No. 72/2020/QH14, 2020

- This comprehensive law sets the foundation for all waste management activities in Vietnam. It mandates segregation, storage, and treatment of hazardous waste, including medical waste. It also emphasizes minimizing waste generation and ensuring compliance with environmental standards.
- This law also establishes a robust policy framework for managing emissions, introducing systems such as emissions trading and carbon taxation. More specifically, it promotes the concept of a circular economy by emphasizing extended producer responsibility (EPR) policies and mandates ministries and local authorities to incorporate circular economy principles into planning, waste management, and recycling strategies. Producers and importers are tasked with recycling obligations for products and packaging.
- Articles 54 and 55 specify guidelines for collecting, disposing, and recycling various waste materials, including plastics.
- Additionally, the law simplifies administrative processes by replacing multiple environmental permits with a unified master license and introducing new procedures for environmental registration. Certain types of waste and environmentally harmful goods are subject to environmental protection taxes, and businesses must comply with recycling requirements or provide monetary compensation for specific products and packaging.

-Circular on Healthcare Waste Management within the premises of healthcare facilities No. 20/2021/TT-BYT

- This circular, which was issued by Ministry of Health, prescribes the classification, collection, storage, and management of medical waste within medical establishments' premises. And it applies to all medical establishments, including hospitals, clinics, and research laboratories.
- Waste is requested to be classified at the point and time of generation, ensuring separation into appropriate packaging or containers as per regulations.
- Collection timing is managed to minimize impacts on patient care areas.
- Facilities must designate secure and appropriate areas for waste storage.

-Circular on Environmental Protection No. 02/2022/TT-BTNMT

- Circular No. 02/2022/TT-BTNMT, issued by the Ministry of Natural Resources and Environment (MONRE) on January 10, 2022, provides detailed regulations for implementing several provisions of the Law on Environmental Protection. The circular aims to enhance environmental management and protection across various sectors.
- This circular details guidelines for integrating environmental protection measures into provincial planning and strategic environmental assessments. It also specifies procedures for the collection, transportation, and treatment of waste to ensure compliance with environmental standards.

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-Joint circular stipulating regulations on Biomedical Waste Management No. 58/2015/TTLT-BYT-BTNMT

- Jointly issued by the Ministry of Health (MOH) and the Ministry of Natural Resources and Environment (MONRE), this circular provides detailed guidance on medical waste management procedures.
- The classification of medical waste is performed according to the principles outlined in Clause 1, Article 6 of this joint circular.
- The collection of medical waste, including infectious waste, non-infectious waste, and common medical waste is specifically regulated under Article 7 of this joint circular.
- Article 8 of Circular 58 regulates the storage of medical waste as follows. Healthcare facilities handling hazardous medical waste must have a storage area that meets the technical requirements stated in Appendix 03(A) attached to Circular 58.
- Regarding transportation, Article 11 allows healthcare facilities to hire external units or transport waste themselves, but specific requirements must be met, such as using sealed or insulated transport vehicles. During transport, if any spills, fires, or explosions occur, immediate environmental response actions must be taken.

- Decree No. 38/2015/ND-CP on the management of wastes and scraps

Clause 1, Article 49 of Decree 38/2015/NĐ-CP stipulates that waste from healthcare activities (excluding wastewater treated through the facility's wastewater system) must be classified at the source. Clauses 2 and 3, Article 49 specifies that special attention must be given to managing infectious waste with the highest level of strictness in healthcare facilities to prevent the spread of pathogens that could impact the environment and public health. If infectious waste is mixed with domestic or common waste, the mixed waste must be managed as hazardous waste.

- Healthcare facilities can choose one of the following hazardous medical waste treatment methods based on planning, economic conditions, and other factors.
    - Centralized treatment: Performed at facilities meeting regulatory conditions, ensuring complete treatment without environmental pollution.
    - Cluster-based treatment: Commonly applied, where medical waste from nearby healthcare facilities is collected and treated at a central healthcare facility.
    - On-site treatment: Used in challenging locations without centralized facilities or where cluster-based treatment is infeasible.

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Annex 2: Kenyan related regulations on medical waste management and treatment

-Environmental Management and Coordination Act (EMCA), 1999

- **Legal Notice No. 121 - Waste Management Regulations, 2006**: These regulations offer a thorough framework for managing all types of waste in Kenya, including medical waste. They cover topics such as waste classification, handling, storage, transportation, treatment, and disposal.
    - Regulation 26 specifically describes the standards for managing healthcare waste, with a focus on labelling, packaging, segregation, and approved disposal techniques
    - These regulations' Schedule 4 enumerates the authorised techniques for handling medical waste, such as chemical disinfection, autoclaving, and incineration.

-Public Health Act, Chapter 242, Laws of Kenya

- This Act establishes the legal foundation for Kenyan public health, including waste management and sanitation regulations. Mandates that all medical facilities ensure handling and disposal of waste is done properly in order to stop the spread of infections.

-Occupational Safety and Health Act, 2007

- The purpose of this Act is to protect the health and safety of employees in all types of workplaces, including medical facilities. Imposes obligations on waste transporters to ensure the safety of personnel who handle hazardous substances
- It mandates that employers give workers the right personal protective equipment (PPE) and maintain a safe workplace, which includes handling and disposing of hazardous materials like medical waste.

-National Guidelines for Safe Management of Health Care Waste, 2nd Edition, March 2024

- The Ministry of Health created these guidelines, which offer helpful advice on how to carry out the legal obligations for medical waste management. The second edition presents an update to the current management of hazards and risks related to healthcare waste handling and incorporates the management of chemicals and POPs
- The subjects covered include waste segregation, colour-coding waste containers, and particular methods of handling and getting rid of various types of medical waste.

- National Guidelines for the Management of Covid 19 Waste, 2022

- Developed by NEMA, following outbreak of Covid 19. Provides updated directives on classification, segregation, securing and disposal of all generated biomedical waste within the country.
- Aligns with international best practices for waste management.

- Biosafety Act, 2009

- Regulates safe handling and disposal of biomedical waste. Includes risk assessments for healthcare-related waste.
-

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Annex 3: Respondents answer on the application of circular economy and the bio-based, bio-sourced materials in medical sectors (traditional hospital and field hospital)

Q. Please describe your current waste management circular economy activities

Anonymous answer No 1. Not as such, mostly promoting recycling of some non-hazardous items, like plastic, metal, etc

Anonymous answer No 2. Majorly land filling method is used but sometimes (infectious and cytotoxic) wastes are always being subjected to incineration.

Anonymous answer No 3. Reduction of waste by educating the community promoting the recycling of plastic Waste

Anonymous answer No 4. Non-existing

Anonymous answer No 5. Paper and bottle manufacturing company, plastic factory, and other local partner

Anonymous answer No 6. Packing material (pallets, carton, wood and aluminium boxes) are reused depending on local conditions.

Anonymous answer No 7. My country does not benefit from the Circulation of the waste and changing to useful products.

Q. If applicable, please specify your organization's plan to adopt bio-sourced or biodegradable materials.

Anonymous answer No 1. We are working on reducing the single use items that we are currently using. This is work in process. And along with this, also reducing the carbon footprint of all the products we use, therefore adopting items with higher components of bio-sourced or biodegradable components. The ambition is to reduce our carbon footprint that we measured in 2019 in half by 2030.

Anonymous answer No 2. Process ongoing of research with our suppliers of medical health care

Anonymous answer No 3. We keep eyes open for biodegradable products.

Anonymous answer No 4. Currently sourcing best system to adopt

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Annex 4: Certification program for HOs and WM service in the survey

Anonymous answer No 1. Certificate from environmental agency and from food and drug authority

Anonymous answer No 2. Certificate of waste management from the ministry of health.

Anonymous answer No 3. Environmental Management Agency of Zimbabwe Hazardous Substances Waste Permit

Anonymous answer No 4. The EPSS intend to obtain several environmental permits and waste management certificates to enhance its compliance with national regulations and improve its waste management practices. These could include Environmental Impact Assessment (EIA) Permit, Solid Waste Management License and Partnerships with Local Authorities: Collaborating with local environmental agencies may lead to obtaining additional permits or certifications specific to regional waste management practices. By obtaining these permits and certifications, EPSS can enhance its credibility, ensure compliance with regulations, and promote sustainable waste management practices in its operations.

Anonymous answer No 5. We are in process of EMT standardization, which is our internal (Red Cross) validation. In line with WHO EMT standards.

Anonymous answer No 6. We get disposal certificates from the ministry of health

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Annex 5: Plug and play example framework and result

The suitable Waste treatment technology is:

Textbox

Incineration

Local Providers of Waste Treatment Technology

Country	Provider Name	Service Offered	Waste Type	County/ City
Finland	Helsinkin municipality	Incineration	Bio-waste	Helsinki
Finland	South-West Finland municipality	Incineration	Non-recyclable Waste	Turku/ Salo
Finland	Pirkanmaa municipality	Incineration	Hazadous Waste	Tampere
Finland	Southern Carelia municipality	Incineration		Lappeenranta
Finland	Pohjanmaa (Central-west area of Finland) municipality	Incineration	Non-recyclable Waste	Vaasa
Finland	Municipality of the Rauma city area	Incineration	Non-recyclable Waste	Rauma
Finland	Westenergy Oy	Incineration	Mixed waste	Kaskinen
Finland	HSY (Helsinki Region Environmental Services Authority)	Incineration	Household waste, Hazardous waste, Plastic, Metal, Organic	Helsinki

Local Regulations on Waste Management

Country	Regulation Name	Regulation Description
Finland	The Finnish Waste Act (646/2011; amendments up to 494/2022)	The Finnish Waste Act holds the highest regulatory position in Finland. However, as a member state of the EU, Finland includes some EU policies (often Finnish regulations are stricter than EU regulation). EU Waste Framework directive sets both overarching targets, as well as specific policies. The Finnish Waste Act 646/2011 underwent amendments in 2021 and 2022.
Finland	The EU Waste Framework directive effects on Finnish Waste Act	The European Union's Waste Framework Directive (WFD) influences the national waste management legislation of its member states, including Finland. Some member states are affected more, some less. The key ways in which the WFD affects the Finnish Waste Act are as follows. The WFD establishes a waste hierarchy that prioritizes waste prevention, reuse, recycling, recovery, and disposal. However, this philosophy was already included in the Finnish Waste Act before the WFD.

The suitable Waste treatment technology is:

Suitable Waste Treatment Technology

Incineration

Local Providers of Waste Treatment Technology

Country	Provider Name	Service Offered	Waste Type	County/ City
Kenya	HEALTH ADVANTAGE K LTD	Incineration	Biomedical/Industrial Waste	Nakuru
Kenya	MATER MISERICORDIAE HOSPITAL	Incineration	Biomedical Waste	Nairobi
Kenya	SUREFLAME INCINERATORS LIMITED	Incineration	Biomedical / Industrial Waste /Contaminated Soil	Machakos
Kenya	COUNTY MEDICAL INVESTMENT COMPANY LTD	Incineration	Biomedical Waste	Embu
Kenya	KENYA ELECTRICITY GENERATING COMPANY PLC	Incineration	Biomedical/Industrial Waste	West Pokot
Kenya	BAMBURI CEMENT.	Incineration	Agricultural Waste/Industrial Waste/Used Oil/Scrap Tyres/Condemned Goods	Machakos
Kenya	CENTURY STEEL FURNITURE LTD	Incineration	Used Oil	Mombasa
Kenya	AGRO CHEMICAL & FOOD COMPANY LIMITED	Incineration	Non-Hazardous Industrial Waste	Kisumu
Kenya	TRANBIZ ENTERPRISES LTD	Incineration	Harzadous/Industrial/Biomedical Waste	Kiambu
Kenya	Aga Khan University Hospital	Incineration	Biomedical Waste	Nairobi

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WORM

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