COVID-19 and Medical Waste Management in the Context of Circular Economy: A Case Study of Egypt

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Abstract

Purpose: This paper seeks to review the influence of COVID-19 on medical waste management and its interplay with CE with a special focus on Egypt as a case study.

Methodology: This paper employs a systematic literature analysis to discover and investigate the relevant studies with the purpose of analysing the effects of COVID-19 on global medical waste management, using Egypt as a case study. For the purpose of this analysis, a top-down approach has been adopted where the study begins with a global review, then proceeds its investigation on Egypt as the case study. In order to assess the viability of CE strategies for strengthening the responsiveness of existing policies and practises to the threats posed by the worldwide pandemic, this study examines more research on the various CE strategies for managing medical waste.

Results: The COVID-19 outbreak has significantly increased global, regional, and local medical waste generation. Given the risks posed by medical waste to the environment and human health, sustainable management and disposal of medical waste constitutes a considerable challenge, especially for developing countries, including Egypt, as the quantity of medical waste significantly outpaces the waste management capacities. CE could aid the transition to an environment-friendly approach of medical waste management through extending the lifespan of medical products and reusing/recycling medical instruments considering the environmental risks linked with the traditional methods of medical waste management. In Egypt COVID-19 has resulted in a number of challenges for medical waste management. Despite the existence of a sufficient regulatory framework, there still exists a number of financial and institutional restrictions. The shift towards CE strategies in Egypt results in different economic, environmental, and social benefits.

Conclusion: This paper reviewed the influence of COVID-19 on medical waste management and its interplay with CE with a special focus on Egypt as a case study. It further analysed the potential prospects for adopting a CE approach in different sectors, including waste management, highlighting its role specifically in mitigating the risks of COVID-19 on medical waste management.

Keywords: *COVID-19, Medical Waste, Medical Waste Management, Circular Economy, Sustainability, Egypt*

1. Introduction

The beginning of the year 2020 witnessed the global viral outbreak of SARS-CoV-2 (COVID-19). The novel virus was announced by the World Health Organization (WHO) as a global pandemic (Sohrabi et al. 2020), as it is characterised by being a highly infectious disease that targets the respiratory system (WHO 2022a). As a result of being highly contagious, there has been an elevation in the number of confirmed cases globally (Lewis 2020; Anderson et al. 2020; Morawska and Cao 2020). The symptoms of the pandemic take the form of mild respiratory illness that requires no special medical attention. Nevertheless, in case of older age groups and individuals with pre-existing conditions, the symptoms become severe, raising the possibility of developing serious illness that requires special medical attention (WHO 2022a). Given its rapid transmission and variations in the severity of its symptoms, there has been an increase in both confirmed cases and mortality rates globally. As of September 2022, the global confirmed cases of COVID-19 reached 607,745,726 cases, while the global mortality rate reached 6,498,747 deaths (WHO 2022e).

The precautionary measures announced by the WHO to contain the pandemic include social distancing, using Personal Protective Equipment (PPE), washing hands using soap and alcohol-based sanitisers. Infected cases with mild symptoms were advised to self-isolate until recovery (WHO 2022a). In addition, healthcare systems worldwide have transformed their medical facilities to quarantine centres to provide medical care for severe cases. COVID-19 and its related precautionary measures have caused a surge in demand for medical services and PPE. Therefore, one of the significant consequences of the global epidemic is the growth of medical waste generation worldwide (Peng et al. 2021; Van Fan et al. 2021; Yang et al. 2021; Zambrano-Monserrate et al. 2020). Consequently, various studies attempted to quantify impacts of COVID-19 on medical waste generation on global (Singh et al. 2022; Yadav et al. 2022), regional (Sangkham 2020; Africa CDC 2022), and local levels (Goswami et al. 2021; Kalantary et al. 2021; Tsai 2021; Andeobu et al. 2022).

Since medical waste is generally categorised into general medical waste and infectious medical waste (WHO 2018), COVID-19 has raised the proportion of infectious medical waste relative to general medical waste, resulting in an additional challenge for medical waste management systems worldwide (Malgorzata et al. 2020). For the purposes of preventing the spread of the virus, safe management of medical waste must be implemented efficiently (Rhee 2020).

In most countries, management of medical waste is governed by strict regulatory framework given the health and environmental risks linked with the mismanagement of such waste. The traditional methods of disposal of medical waste include source separation, transportation, treatment, disinfection, and disposal (Windfeld and Brooks 2015; Akter 2000; Almuneef and Memish 2003). These methods, despite being effective in limiting the risk of COVID-19 transmission through medical waste, they are not regarded as environmentally efficient. Through the discharge of infections and harmful contaminants into the environment, the treatment and disposal of healthcare waste could indirectly result in health risks. For instance, incineration is regarded as the most commonly used methods of handling medical waste (Lee and Huffman 1996; Lee, Huffman, and Nalesnik 1991; Windfeld and Brooks 2015). Nevertheless, poor incineration techniques cause discharge of airborne contaminants and the formation of ash residues (Lee and Huffman 1996; Singh and Prakash 2007; Xie et al. 2009). Additionally, improper collection and treatment techniques combined with lack of knowledge regarding COVID-19 decontamination could increase the risk of viral transmission (Nghiem et al. 2020; Kulkarni and Anantharama 2020).

Studies analysed the impacts of the global pandemic on sustainable development (Wang and Huang 2021; Heggen et al. 2020; Fenner and Cernev 2021). Among the observed adverse impacts of COVID-19 on sustainability are global recession, disruptions in global supply chains, increased vulnerability of livelihoods, financial pressures on public budgets resulting from increased healthcare expenditures (Naidoo and Fisher 2020; Bhagat et al. 2020; Khan et al. 2020). Additionally, studies revealed the short-term positive environmental effects of COVID-19 on GHG emissions, deforestation, surface water, noise reduction, pollution, and air quality (Braga et al. 2020; Jiang et al. 2021; Pakravan-Charvadeh et al. 2021; Zambrano-Monserrate et al. 2020; Chakraborty and Maity 2020). On the contrary, the global pandemic has resulted in various environmental risks including, emissions from increased reliance on incineration, increased landfilling, reduced recycling (Zambrano-Monserrate et al. 2020), increased use of hazardous chemical disinfectants (Zhang et al. 2020; Wang et al. 2020; Chang et al. 2020), and an increase in medical and plastic waste generation (Ding et al. 2021; Abu-Qdais et al. 2020; Prata et al. 2020; Nowakowski et al. 2020; Liu and Schauer 2021).

Circular economy (CE) could play an effective role in enhancing the sustainability of medical waste management to mitigate the risks posed by the global pandemic. It is is regarded as an economic model that addresses the three main pillars of sustainable development through resource conservation, sustainable waste management, and wealth generation (Naidoo and Fisher 2020; UNCTAD 2022; Ellen Macarthur Foundation 2021). Considering the impacts of the global pandemic on sustainability, governments undertook a series of emergency packages to alleviate such impacts (Ibn-Mohammed et al. 2021). The opportunity cost that emerges in this regard is whether these packages should prioritise economic recovery and development by accelerating linear and business as usual models, or should they shift their approach to developing a resilient and sustainable low-carbon CE? (Gates 2020; Guerrieri et al. 2022; Piguillem and Shi 2020)

Various studies have analysed the role of CE in waste management systems (Pires and Martinho 2019; Malinauskaite et al. 2017; Tomić and Schneider 2020), particularly medical waste (Kane et al. 2018; Voudrias 2018; Teymourian et al. 2021; Cobo, Dominguez-Ramos, and Irabien 2018; Chauhan et al. 2021). Despite the distinct nature of medical waste and the priority to restrict transmission of infections and contain the global pandemic, transition to CE in managing medical waste could offset the environmental and health risks of COVID-19 on medical waste management (WHO 2019). CE could lower the risk of exposure to infections associated with medical waste management through improving hygiene practices (IGES 2021). In addition to cost savings for medical facilities, CE strategies could minimise the environmental risks associated with some traditional methods of medical waste management, including emissions of pollutants associated with incineration (IGES 2021; Kane et al. 2018).

In Egypt, the total confirmed cases of COVID-19 were estimated to be 515,348 cases, while the mortality rate reached 24,796 deaths as of September 2022 (WHO 2022b). As the case with all countries, the government announced the precautionary measures and emergency plans to contain the pandemic and offset its health risks (Cabinet of Egypt 2020). In response to the outbreak, the country expanded the scope of medical services and established quarantine units in healthcare facilities to provide medical attention for severe cases (Cabinet of Egypt 2020).

As the case with other developing economies, the outbreak of the global pandemic caused a major disruption for the Egyptian economy (IMF 2021). Precautionary measures enforced by the government in the form of lockdowns and social distancing have resulted in a short-term decline in the economic activity (IMF 2021; Breisinger et al. 2020; Breisinger et al. 2020; Rezk et al. 2020). The influence of COVID-19 on economic sectors was not, nevertheless, uniform; some sectors, including tourism (Breisinger et al. 2020), for instance, were severely impacted as compared with others. In response to such risks, the Egyptian government along with the Central Bank of Egypt undertook a series of stimulus packages in the form of expansionary fiscal and monetary policies.

Waste management constitutes a major challenge for Egypt's sustainable development. Improper waste treatment poses major health and environmental risks. During last decade, government has intensified its focus on addressing the deficiencies in the country's waste management system (Ahram Online 2019; Ibrahim and Mohamed 2016; Milik 2021). The main drivers of the country's increase in the volume of solid waste include population growth, urbanisation, and economic growth (Ibrahim et al. 2020). Egypt generates 5.4 million tonnes of plastic waste annually, which represents 13% of the country's total waste composition (WWF 2019; Noureldin 2020). In terms of solid waste, the country's total solid waste generation was estimated to be 22 million tonnes per year, with a daily average of 50k-60k tonnes of solid waste (Enterprise 2020). Management of solid waste is characterised by being a costly procedure; the average cost of collection of solid waste is approximately EGP 480 per tonne (Enterprise 2020).

The regulatory framework of waste management in Egypt incorporates a collection of legislations, regulations, institutions, strategies, plans, and programs. For instance, the country promulgated its first waste management law entitled Waste Management Regulation Law in 2020 (*Waste Management Regulation Law* 2020). The primary objective of the law and its executive regulation is to provide a framework for a sustainable and integrated management of different types of waste, including hazardous and non-hazardous waste, and specify how waste disposal would be financially sustainable. (*Waste Management Regulation Law* 2020).

Several studies attempted to estimate the effect of COVID-19 on medical waste generation in Egypt (Mostafa et al. 2021; Gawish 2020; Torieh et al. 2020; El-Ramady et al. 2021). An increase in the quantity of medical waste induced by the global epidemic would entail safe and proper management to minimise the risks associated with such waste (SIS 2021). Addressing the environmental and health dimensions of medical waste management entails a shift from conventional methods of medical waste management, including incineration (Shouman 2013), to a 3R approach proposed by CE.

The applicability of a CE approach in Egypt is analysed in the literature (Maamoun 2021; Mahmoud et al. 2020; Roberts and Abdelaty 2021; Schröder 2020). The framework that assists in the transition for CE includes Waste Management Regulation Law, Sustainable Development Strategy, the National Action Plan for Sustainable Consumption and Production, and the National Solid Waste Management Program (Maamoun 2021). This framework is sector-specific; it focuses on providing the technical capacities in targeted sectors, including industry, agriculture, and waste management (Roberts and Abdelaty 2021). In general, studies concluded that a proper transition to CE in Egypt could bring about positive effects on economic (Mahmoud et al. 2021; Schröder 2020), environmental (Maamoun 2021; Ngan et al. 2019), and social (Mahmoud et al. 2021; Roberts and Abdelaty 2021) pillars of sustainability.

This paper seeks to review the influence of COVID-19 on medical waste management and its interplay with CE with a special focus on Egypt as a case study. The paper proceeds to analyse, based on the surveyed literature, the existing framework for medical waste management, including legislations, regulations, policies, plans, and strategies, in response to the global pandemic. Finally, it reviews the potential prospects for adopting a CE approach in different sectors, highlighting its role specifically in waste management. It argues that in the light of the challenges imposed by the global pandemic on medical waste management, a proper adoption of CE-based solutions could result in optimisation of the existing waste management systems to minimise the environmental and health risks associated with the global pandemic. It further argues that a CE approach could catalyse sustainability efforts in Egypt in the light of a sufficient legal, institutional, and financial framework.

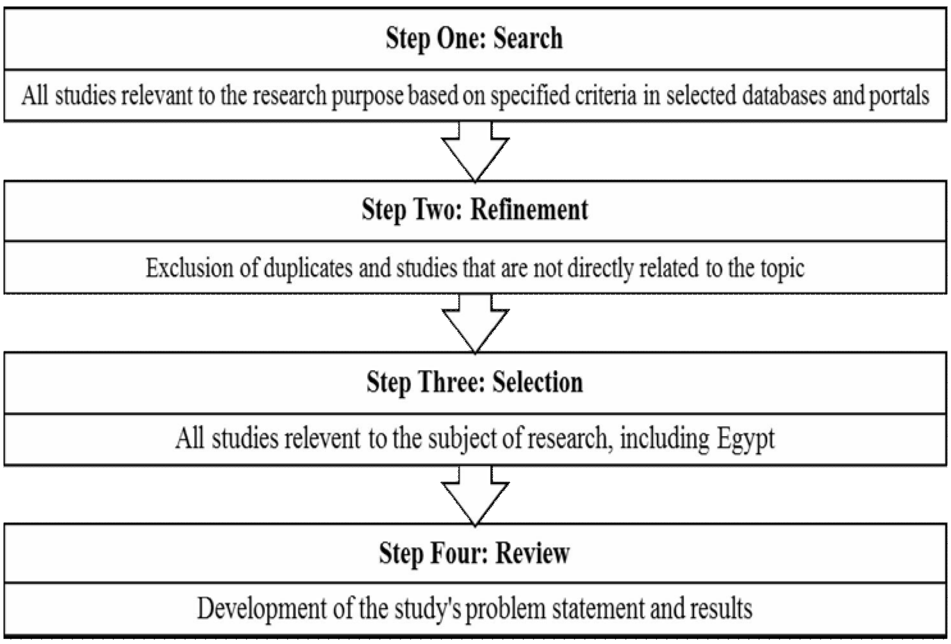
This study is divided into ten main sections. Section 2 represents the methodological framework of the papers, which takes the form of a systematic literature review. A conceptualisation of both medical waste and CE is presented in Section 3. Section 4 examines the effects of COVID-19 on global medical waste generation. In Section 5, an analysis has been conducted, based on the existing literature, on the applications of CE strategies in medical waste management. Section 6 examines the Egyptian regulatory framework for waste management. The effects of COVID-19 on medical waste management in Egypt are discussed in Section 7, which includes its impacts on medical waste generation and current practices of medical waste management adopted in response to these impacts. Section 8 discusses the potential role of CE strategies and measures in Egypt. Finally, Section 9 presents the results and discussion, while Section 10 concludes.

2. Methodology

This paper employs a systematic literature review to discover and investigate the relevant studies with the purpose of analysing the effects of COVID-19 on global medical waste management, using Egypt as a case study. For the purpose of this analysis, a top-down approach has been adopted where the study begins with a global review, then proceeds its investigation on Egypt as the case study. In order to assess the viability of CE strategies for strengthening the responsiveness of existing policies and practises to the threats posed by the worldwide pandemic, this study examines more research on the various CE strategies for managing medical waste. In terms of Egypt, the article examines the country's waste management regulatory framework, notably medical waste, by investigating existing legislations, rules, policies, strategies, and plans. The remainder of the study surveys analyses and reports on the implications of COVID-19 on the generation and management of medical waste in Egypt. It additionally reviews the latest studies on the framework, prospects, and challenges of adopting a CE approach in Egypt. Data on the generation, management, and disposal of medical waste have been obtained from official websites of relevant international organisations including, World Health Organization (WHO), United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), United Nations Conference on Trade and Development (UNCTAD), World Bank, European Parliament, and European Environmental Agency. In Egypt, government portals explored include Cabinet of Egypt, Ministry of Environment (MOE), Ministry of Health (MOH), State Information Services (SIS), Egypt Sustainable Development Strategy 2030 (SDS 2030), and National Solid Waste Management Programme (NSWMP).

For this purpose, the study relied on secondary data derived from journal articles, conference proceedings, policy papers, press releases, newspaper articles, reports, reliable websites, and government and official documents, including legislations, regulations, policies, programs, and strategies. The authors focused on numerous methodological approaches of literature searches depending on the following search parameters: English language, time scope, and a combination of keywords linked with the purpose of this study, including *COVID-19, Pandemic, SARS-CoV-2, Medical Waste, Clinical Waste, Medical Waste Generation, Medical Waste Management, Circular Economy, Medical Waste Management in Egypt, Circular Economy in Egypt.* The search was conducted in major databases, including ScienceDirect, Scopus, Web of Science, and Google Scholar. Following the search process, results were further refined to exclude duplicate papers and those that are not directly related with the subject of the study. This process resulted in the development of the study's theoretical framework, problem statement, and results. The temporal scope of the study involves the period of the outbreak of the global pandemic starting from early 2020. The spatial scope of this review highlights Egypt as the main subject of the case study. Figure 1 outlines the framework of the paper's methodological approach.

Figure 1: A Framework of the Study's Methodology



3. Background: Conceptualisation of Medical Waste and Circular Economy

3.1 Medical Waste

Anthropogenic activities generate various forms of waste. A considerable amount of waste is produced as a result of manufacturing and consumption. Waste classification could be based on several criteria. Industrial waste, construction waste, medical waste, e-waste, agricultural waste, radioactive waste, and waste from extraction activities are the most common types of waste. In this paper, we examine both medical and electronic waste.

Medical waste refers to waste resulting from all medical activities within or outside of a hospital, including medication, clothing, devices, sharp instruments, and syringes (Shareefdeen 2012; Priya et al. 2013; ICRC 2011). Healthcare facilities and hospitals generate a substantial volume of medical waste, including gloves and disposable plastics. If these items were discarded or abandoned in an unsafe manner, the risks to public health and the environment would increase dramatically (UNEP 2020). In addition, dangerous chemicals emerging from medical waste may cause severe physical injury to patients, society, and the environment. (Stringer 2021).

According to the severity or origin of the waste, medical waste is categorised as follows: (ICRC 2011; Priya et al. 2013):

1. Contaminating waste: It refers to materials and equipment that have come into touch with patients, as they could infect others and spread the infection.
2. Pathological waste: It involves blood and human tissues resulting from surgical procedures.
3. Pharmaceutical waste: It refers to waste from pharmaceutical use such as bottles, cartons, expired materials, and contaminated materials that cannot be reused.
4. Bio-hazardous blood waste: It refers to hazardous waste, such as blood and other bodily fluids, disposed by healthcare facilities.

Table 1 lists the different categories of medical waste and their respective description.

Table 1: Different Types of Medical Waste

Type of Waste	Definition & Examples
"Infectious Waste"	It refers to waste that is currently or potentially contaminated with pathogens, including lab waste and waste resulting from medical tests, for instance
"Pathological Waste"	It refers to human body secretions or tissues, including blood and other bodily fluids; and human organs
"Sharps"	It refers to the disposal of sharp instruments and equipment, including shattered glass, needles, knives, blades, infusion sets
"Pharmaceutical Waste"	It refers to waste generated from consumption of pharmaceutical products, including unused or expired medications; and pharmaceutically contaminated packages or bottles
"Genotoxic Waste"	It refers to hazardous waste resulting from cytostatic drug residues in addition to urine, stool, and vomit of patients subject to chemical and radioactive therapy
"Chemical Waste"	It refers to chemically-contaminated waste, including Outdated or unused disinfectants, lab chemicals, and film developers

Type of Waste	Definition & Examples
"Wastes with Hight Content of Heavy Metals"	It includes waste from malfunctioning or damaged medical devices, including damaged thermometers, blood pressure gauges, and batteries
"Pressurized Containers"	It refers to waste of empty or full pressurized liquid, gas, or powdered material containers, such as aerosol cans and gas containers.
"Radioactive Waste"	It refers to radioactive waste generated during diagnostic and therapeutic procedures, such as medical equipment contaminated with traces of specific isotopes, clothing, biological material, and the radiation source for radiotherapy, as well as body organs and fluids of patients undergoing radiotherapy.

Source: (Prüss-Üstün 1999)

There are numerous methods for disposing of medical waste. They include categorizing materials as hazardous and nonhazardous, which is regarded as a useful practice since it prevents the contamination of hazardous waste with nonhazardous waste. Waste is often classified depending on its contents, quantity, and methods of eliminating toxic gases and fumes (Shareefdeen 2012). Another strategy for minimising the amount of medical waste is decontamination. Based on this strategy, medical waste is burned in ovens to eliminate any hazardous content and is eventually transformed to ashes. This procedure is not advised for all types of medical waste, nevertheless (Shareefdeen 2012).

3.2 Circular Economy

The term circular economy (CE) refers to a production and consumption system that promotes the sustainability of resources and products by extending their lifespan. It enhances the efficient use of products and resources through recycling and reusing instead of wasting them (UNCTAD 2022; Ellen Macarthur Foundation 2021; European Parliament 2022; EPA 2021; EIB 2020). Adopting CE entails a shift towards sustainable production and consumption patterns, including reliance on renewable energy and resources (Ellen Macarthur Foundation 2021; Arthur et al. 2022). Among the strategies that contribute to extending the lifespan of products and resources are sharing, leasing, reusing, repairing, refurbishing, and recycling (European Parliament 2022; EIB 2020).[1]

CE is generally regarded as an effective solution for several global challenges, including climate change, waste management, biodiversity loss, pollution, and depletion of resources (Ellen Macarthur Foundation 2022; Arthur et al. 2022). In essence, CE promotes the conversion of conventional industrial and economic

(1) CE is associated with the term “Cradle-to-Cradle” as opposed to “Cradle-to-Grave”. Cradle-to-Cradle is a method of designing and manufacturing that promotes sustainable development through shifting production towards re-use rather than disposal. Consequently, and in contrast with a cradle-to-grave system of take, make, and waste, cradle-to-cradle employs a system of take, make, retake, and remake.

activities into more regenerative ones, which sustains the highest value of these activities over time while also reducing waste (EPA 2021). Three fundamental concepts guide CE: restricting waste and pollution, reusing and recycling resources and products, and nature regeneration (Ellen Macarthur Foundation 2021; Arthur et al. 2022).

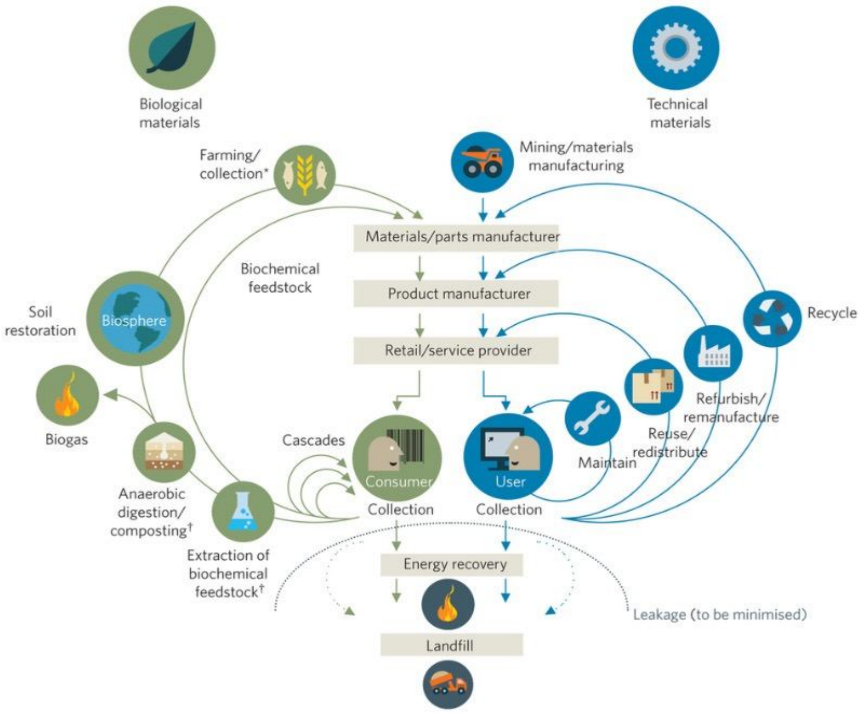
CE is generally contrasted with linear economy which relies on business-as-usual practices of production and consumption. These practices guarantee ongoing consumption and production patterns by limiting the life cycle of products and resources, where resources are transformed into products and eventually turn into waste (European Parliament 2022; EIB 2020). CE, therefore, results in increased accessibility and reduced prices of resources and products as compared with linear economy that requires extraction of new resources for production (European Parliament 2022; Arthur et al. 2022).

CE is generally based on two cycles: biological and technical. The biological cycle aims at restoring wasted products and resources to nature. The technical cycle relies on marketing and designing strategies that eliminate waste of materials and products (MacArthur 2013). By combining both cycles, CE attempts to eliminate waste during the entire extraction-production-consumption cycle while optimizing the utilization of pure, non-toxic materials and products. For the purpose of increasing their lifespan, products are designed and promoted in a manner that enables their maintenance, reuse, repair, or refurbishment (MacArthur 2013). Figure 2 illustrates the components of both biological and technical cycles of CE.

CE, consequently, shifts economic growth from the inefficient use of resources towards sustainable production and consumption patterns that preserve these resources. In addition, it offers a mechanism for businesses to mitigate potential risks associated with their resource and material supply chains and boost their resilience to supply shortages and price volatility (EIB 2020). This will minimise reliance on natural resources, stimulate innovation, and boost competitiveness. Additionally, the circular economy presents a potential for economic and industrial revitalization, as well as an increase in investments (EIB 2020).

In the context of CE, it is important to distinguish between three different mechanisms of resource flow: closing resource loop, slowing down resource loop, and narrowing resource loop. Slowing resource loop could be achieved by reuse of products and materials, which refers to extending their lifespan through designing durable goods in addition to provision of services that could contribute to such extension, including repair, maintenance, and technical upgrading (Bocken et al. 2016; Jensen 2018). Closing resource loop is based on generating a cyclical flow of resources through recycling, with the goal of closing the loop between post-use waste and production (Bocken et al. 2016). Finally, narrowing resource loop is often associated with resource efficiency and resource productivity. It relates to limiting resource use per unit of output. (Bocken et al. 2016). To achieve this purpose, the term "resource productivity" emerges to draw a link between resource use and its environmental impact. Enhancing resource productivity is, consequently, accomplished through resource efficiency, where reducing the amount of resources utilized per product results in lower environmental impact per product (Bocken et al. 2016).

Figure 2: Biological and Technical Cycles of CE

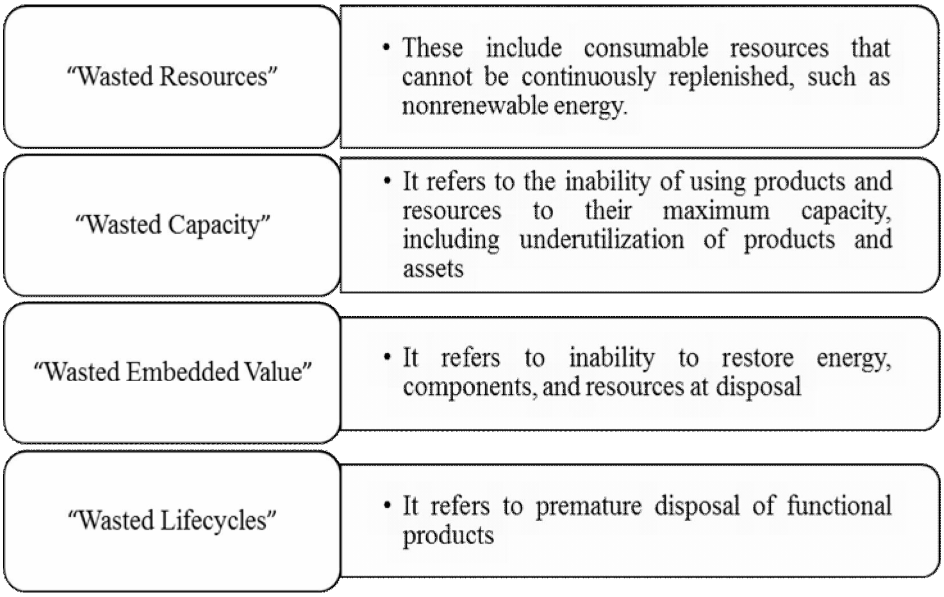


Source: (MacArthur 2013)

It must be noted that narrowing resource loops is distinct from slowing and closing resource loop, as resource efficiency is one of the tactics typically employed by linear economy. (Bocken et al. 2016). Contrary to closing and slowing resource loop, narrowing resource loop neither impacts the flow rate of resources nor does it involve strategies for cyclic use of resources, including recycling and reuse.

To illustrate the mechanism of CE, Lacy, Long, and Splinder (2020) identified four categories of wasted value and the proposed CE business models linked with each type. Based on their findings, waste could be classified into four types according to value: wasted resources, wasted capacity, wasted embedded value, and wasted lifecycles. For each category of waste, CE emerges to propose numerous approaches or strategies with the aim to close, slow, or narrow resource loops. These strategies are target-specific and they range from recycling, reuse, energy and component harvesting, sharing, co-owning, resource pooling, and utilization of renewable sources of energy; they further involve reliance on various services that extend the lifespan of products, including maintenance and repair. Figure 3 illustrates the various types of wasted value. Table 2 displays the planned CE procedures for each type of waste.

Figure 3: Types of Waste



Source: (MacArthur 2013; Lacy et al. 2020)

Table 2: Types of Waste and Proposed CE Approaches

Type of Waste	CE Approach
"Wasted Resources"	Reliance on renewable and bio-based resources
"Wasted Capacity"	Expanding the scope of sharing, co-ownership, and resource pooling
"Wasted Embedded Value"	Expanding the scope of recycling, component collection, and energy recovery
"Wasted Lifecycles"	Provision of maintenance, repair, and remanufacturing

Source: (MacArthur 2013; Lacy et al. 2020)

The foundation of circular economy is based on a number of drivers including (Lacy and Rutqvist 2015):

1. Resource depletion: There are concerns about witnessed shortages in vital natural resources and raw materials driven by a rapid increase in global demand for resources. This increased demand aims fulfill the needs of growing production and consumption patterns led by industrialization. Sustainability, therefore, entails a transition in the current trends of resource use towards more efficient ones.
2. Technology: The adoption and deployment of recent circular economy business models, generally focused on sharing, leasing, recycling, and remanufacturing is largely facilitated by the advent of new technologies, including AI, IoT, and big data tools. Innovative technical methods make it feasible to trace products and materials across the course of their lifecycle, resulting in longer usage and, ultimately, higher value. Currently, developments in production and manufacturing, including 3D printing and AI, are enhancing design and manufacturing capabilities.
3. Urbanization: The ongoing global large-scale urbanization contributes to the adoption and development of circular systems. This is attributed to the fact that urban areas, in contrast with urban areas, have the capability to develop reuse, collection, and recycling schemes for products, materials, and

resources, which could effectively close resource loops and stimulate the implementation of asset-sharing programmes and reusing products.

In addition to the aforementioned drivers, CE is currently recognized as a strategy for climate change mitigation (Bora et al. 2020; Cantzler et al. 2020; Christis et al. 2019; Gallego-Schmid et al. 2020; Khanna et al. 2022). The adoption of CE strategies, including reuse, recycle, and remanufacture, contribute significantly to waste reduction, resource consumption, and hence reduction of GHG emissions. Transition to CE targets reducing carbon dioxide emissions from selected sectors, including construction, energy, industry, transportation, and land use (Cantzler et al. 2020). For instance, Gallego-Schmid et al. (2020) concluded a significant role of CE in eliminating GHG emissions from the construction sector through slowing, closing, and narrowing resource loops. The impact of CE on GHG emissions reduction ranged between significant reductions through slowing loops (up to 99% per functional unit), moderate to significant reductions through closing loops (30%-50%), and significant reductions through narrowing loops (9.23-19.82 Mt CO_2 eq during 2023-2027 in the UK) (Gallego-Schmid et al. 2020). In the energy sector, CE eliminates GHG emissions through closing the resource loop by reliance on renewable energy and biofuels (Englund and André 2022).

Furthermore, CE could be used as a strategy for climate change adaptation in the construction sector (Englund and André 2022). Extreme weather events induced by climate change result in substantial damage for buildings and infrastructure, that would require extraction and utilization of new resources and materials. Therefore, a circular climate change adaptation could be achieved through urban planning that involves nature-based solutions, including expansion of green areas and green infrastructure to address the impacts heatwaves, for instance; this is conditional that these solutions rely on renewable, reused, or recycles resources (Englund and André 2022).

CE is generally associated with sustainability. Circular supply chains and business models are a key contributor to environmental sustainability, particularly in the context of the manufacturing industry. (Rashid et al. 2013). Additionally, a number of studies view CE as a prerequisite for environmentally sustainable economic growth (Bakker et al. 2014; UNEP 2006). Contrary to previous perceptions, Nakajima (2000) and Bonviu (2014) concluded that CE is an essential but insufficient component of the three key dimensions of sustainable development, including economic growth, employment, and resource efficiency and productivity; CE must be supplemented by major systemic shifts and transformations to ensure sustainability (Nakajima 2000; Bocken et al. 2014; Weissbrod and Bocken 2017). To conclude, the relationship between CE and sustainability can be classified as conditional and/or beneficial; in other occasions, CE is regarded as a trade-off for sustainability (Geissdoerfer et al. 2017). Most studies focused, nevertheless, on the influence of CE on the environmental dimension as opposed to other dimensions of sustainability.

4. COVID-19 and Medical Waste Generation: A Global Perspective

Various studies attempted to estimate medical waste generated during the COVID-19 outbreak (WHO 2022; Benson, et al. 2021; Goswami et al. 2021; Liu et al. 2020; UNDP 2020). These studies investigated the effects of the global pandemic on the growth of medical waste and its management on global, regional, and local bases.

According to WHO (2022c), the outbreak of COVID-19 and the resulting rise in global infection rates have resulted in a twofold burden on the healthcare sector: a growth in medical waste generated and a decreased efficiency to control medical waste. For instance, COVID-19 has amounted to an elevation in hazardous medical waste by 3.4 kilograms per bed on daily basis (UNDP 2020). Consequently, the volume of hazardous medical waste has increased tenfold as compared to the pre-pandemic era average, which was between 0.2–0.5 kilograms per bed per day (UNDP 2020). These results emphasize significant and unexpected growth in medical waste that have emerged in certain cities and nations as a result of the global pandemic.

In addition, Benson et al. (2021) concluded that there has been a marked growth in the global consumption of PPE, especially single-use facemasks, by roughly 3.4 billion facemasks that were disposed on daily basis in 2020, which resulted in a substantial increase in quantity of plastic waste. The rapid and unexpected surge in COVID-19 cases worldwide induced severe declines in PPE supplies and price hikes by roughly 300% (WHO 2020). As a result of stockpiling that occurred in high-income nations, In low- and middle-income countries with limited manufacturing capabilities, PPE shortages were extremely severe (WHO 2020).

In Asia, several studies analysed the influence of COVID-19 on various forms of medical waste (Goswami et al. 2021; Liu et al. 2020; Sangkham 2020). On a continental level, Sangkham (2020) concluded that the total medical waste generated in Asia during the global pandemic was estimated to be 16,659.48 tonnes daily. By ranking the countries that produces the highest quantity of medical waste. India is ranked first with a total of 6,491.49 tonnes/day, Iran is ranked second with a total of 1,191.04 tonnes/day, Pakistan with a total of 1,099.30 tonnes/day, Saudi Arabia with a total of 1,083.17 tonnes/day, Bangladesh with a total of 927.81 tonnes/day, and finally, Turkey with a total of 908.07 tonnes/day. Countries that generate relatively limited medical waste included Japan (130.54

tonnes/day), South Korea (56.50 tonnes/day), and Hong Kong (12.54 tonnes/day) (Sangkham 2020, 3). The study indicated that the increase in medical waste generation was mainly attributed to the rise in number of infections (Sangkham 2020, 3).

Goswami et al. (2021) analysed the effects of the global epidemic on bio-medical waste in India. Based on this study, the quantity of bio-medical waste created mainly by public hospitals, laboratories, and quarantine centres has increased significantly (Goswami et al. 2021). The study concluded a sharp increase in bio-medical waste as a result of the global pandemic; this increase was estimated to be fifteen times as compared with the pre-pandemic era (from 0.3kg–1kg/bed/day to 4.5kg-15 kg/bed/day) (Goswami et al. 2021).

In China, COVID-19 has resulted in substantial quantity of medical waste. China manufactured 116 million single-use masks per day in February 2020; this is considered a 12-fold growth in the quantity of disposable masks produced as compared with the pre-pandemic era (Chen et al. 2021). Liu et al. (2021) examined China's overall capacity of medical waste management and outlined the various medical waste management practises during January-June 2020. In order to accomplish this, the study analysed the volume and capacity of medical waste disposal in China during the course of the study period. On March 28th, 2020, China reached its maximum daily collection of medical waste with 3590.9 tonnes, and between January 20 and June 6, 2020, 447 kilo tonnes of medical waste were disposed of (Liu et al. 2021). China's medical waste disposal capacity increased by 25.8% from the pre-epidemic level of 4902.8 tonne per day to 6167.3 tonne per day (Liu et al. 2021). On February 24th, 2020, 403.7 tonnes of medical waste were generated by designated medical facilities, comprising nearly 21.6% of the total collection for that day (L. Liu et al. 2021). The percentage of medical waste from these medical institutions significantly dropped to 5.4% on April 25th, 2020 (Liu et al. 2021).

In addition, Tsai (2021) evaluated the effects of COVID-19 on the generation of medical waste in Taiwan. The scope of the study included analysing the trend of medical waste generation during the years 2016-2019 as compared to the pandemic era, especially the first half of the year 2020. The study categorised medical waste into two types: general medical waste and hazardous or infectious medical waste. It concluded an increasing trend in medical waste generation between 2016 and 2019, which was mainly attributed to growth in medical services during this period (Tsai 2021). Taiwan's medical waste generation increased moderately between 2016 (35,747 metric tonnes) and 2019 (40,407 metric tonnes), reflecting an average annual rise of 4.17 % (Tsai 2021). The study further concluded a positive correlation between growth in the rate of COVID-19 infections and medical waste generation. By comparing the quantity of medical waste generated between the first half of

2019 and the first half of 2020, it is evident that the amount of medical waste generated in the first quarter of 2020 (8832 metric tonnes) increased by 4.6% as compared with the first quarter of 2019 (8447 metric tonnes) (Tsai 2021). Medical waste generation, on the other hand, declined in the second quarter of 2020 compared to compared to the same period in 2019 from 8888 metric tonnes to 8842 metric tonnes, amounting to a −0.5% reduction (Tsai 2021). In the first half of 2020, nevertheless, the volume of medical waste increased at a slower rate than it did annually throughout 2016-2019, according to the study.

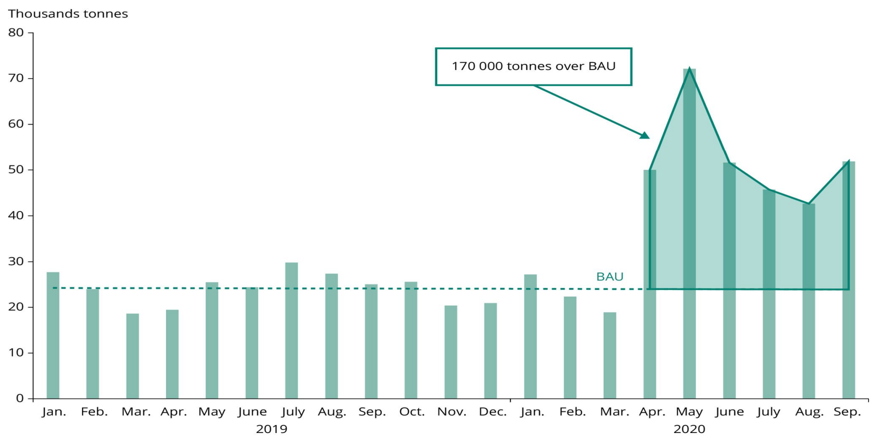
Based on an analysis of medical waste production in five Iranian hospitals during the global epidemic, Kalantary et al. (2021) concluded an average increase in medical waste generation on daily basis in the surveyed hospitals by 102%. On daily basis, the medical waste growth rate varied between 0.82 kg per bed and 3.5 kg per bed. (Kalantary et al. 2021). The overall rates of waste generation per patient bed before and during the outbreak were estimated to be 1.77 and 3.46/bed/day, respectively (Kalantary et al. 2021).

In Australia, Andeobu et al. (2022) concluded that an increase in the use of PPE, masks, and sanitizers, imposed by the precautionary measures related to COVID-19, have resulted in a substantial growth in both infected and noninfected medical waste generation. The study further asserted that the growth of medical waste generation was linked with increased number of confirmed cases in some major cities, including Sydney and Melbourne (Andeobu et al. 2022). It was estimated that elderly care facilities in Victoria produce weekly medical waste equivalent to a 240-liter container; elderly care facilities with confirmed cases generate medical waste up to 12 240-liter containers per day, or 84 containers weekly (Department of Health and Aged Care 2020). According to Terzon (2021), medical waste generation in Victorian hospitals increased between 25% and 130% during the outbreak. Numerous countries, including Australia, have reported that the amount of waste generated during the epidemic period has grown by 10 to 20 times compared to pre-pandemic levels, indicating the considerable effect of COVID-19 on medical waste generation (Andeobu et al. 2022). In Sydney hospitals, the epidemic caused a 35% rise in medical waste (Andeobu et al. 2022).

In the Americas, COVID-19 has further resulted in a substantial increase medical waste generation, which is deemed hazardous, posing an elevated risk of infection spread (Yadav et al. 2022). The large-scale use of PPE entails the reliance on various strategies to ensure that waste is discarded safely after use, considering the fact that PPE is single use and highly infectious. Yadav et al. (2022) deduced, based on a quantitative analysis of the effect of the global pandemic on medical waste generation in selected countries in the America, that the USA produced 8055.03 tonnes of hazardous medical waste every day during the epidemic, reaching approximately 805,502.84 tonnes in 100 days. The study additionally concluded similar increases in medical waste generation in Brazil (2774.35 tonnes per day), Mexico (358.75 tonnes per day), Argentina (454.41 tonnes per day), and Colombia (550.63 tonnes per day) (Yadav et al. 2022).

Additionally, there has been increasing trends in the usage of PPE, including face masks, in medical settings and by the general public as a consequence of Europe's responses to COVID-19 (European Environmental Agency 2022). Due to the lack of data on the quantity of medical waste generation, the volume of COVID-19-related medical equipment that is imported into Europe can be used to quantify the growth in the utilisation of such equipment, and therefore, quantify the amount of medical waste generated (Graulich et al. 2021). By comparing the overall imports of face masks to the European Union between the pre-pandemic era and during the pandemic, it is evident that COVID-19 has resulted in a growth in the size of these imports; Before the pandemic, the European Union imported 289 000 tonnes of facemasks in 2019, while between April and September 2020, the European Union imported a total of 170 000 tonnes of face masks as compared with business-as-usual net imports (Graulich et al. 2021; European Environmental Agency 2022). Figure 4 illustrates the total EU imports of face masks during the pandemic as compared with pre-pandemic era.

Figure 4: EU Imports of Face Masks (January 2019 – September 2020)



Source: (European Environmental Agency 2022; Graulich et al. 2021)

Finally, PPE are now considered standard clothing throughout Africa, especially among health personnel; they represent 75% of the medical waste in the African region (WHO 2022d). Due to the consumption of 435 million COVID-19 vaccines, the remaining 25% of the continent's medical waste is composed of hazardous vaccination waste, including bottles, safety boxes, syringes, and sharps (WHO 2022b). By categorising healthcare facilities into inpatient and outpatient care facilities, Daily waste generation for COVID-19 patients in inpatient facilities averages 2.5 kg as compared to 0.2 kg/day in outpatient facilities (Africa CDC 2022). For instance, the total amount of medical waste generated in South Africa was estimated to be 269.12 tonnes per day, while in Egypt, the amount of medical waste generation was estimated to be 128.54 tonnes per day (Yadav et al. 2022).

Table 3: Medical Waste Generation in Selected Regions/Countries During COVID-19

Region	Country	Type of Medical Waste	Volume/Measurement	Reference
Asia	India Iran China Taiwan Japan	Hazardous Hazardous Bio-medical Waste Hazardous All Hazardous All Hazardous	16,659.48 tonnes/day 6,491.49 tonnes/day 4.5kg-15 kg/bed/day (15-fold increase) 1,191.04 tonnes/day 3.5 kg/bed/day (102% increase) 332.59 tonnes/day 8832 metric tonnes (4.6% increase during first half of 2020) 130.54 tonnes/day	(Sangkham 2020) (Sangkham 2020) (Goswami et al. 2021) (Sangkham 2020) (Kalantary et al. 2021) (Sangkham 2020) (Tsai 2021) (Sangkham 2020)
Australia		All	10- to 20-fold increase	(Andeobu et al. 2022)
Europe	Italy France Spain Germany	All Hazardous All All All	4.1 kg/bed/day 45.09 tonnes/day 3.3 kg/bed/day 4.4 kg/bed/day 3.6 kg/bed/day	(Singh et al.2022) (Yadav et al. 2022) (Singh et al. 2022) (Singh et al. 2022) (Singh et al. 2022)

Region	Country	Type of Medical Waste	Volume/Measurement	Reference
Americas				
	United States	All	8.4 kg/bed/day	(Singh et al. 2022)
		Hazardous	8055.03 tonnes/day	(Yadav et al. 2022)
	Brazil	All	3.3 kg/bed/day	(Singh et al. 2022)
		Hazardous	2774.35 tonnes/day	(Yadav et al. 2022)
	Argentina	Hazardous	454.41 tonnes/day	(Yadav et al. 2022)
	Mexico	Hazardous	358.75 tonnes/day	(Yadav et al. 2022)
	Canada	All	8.2 kg/bed/day	(Singh et al. 2022)
Africa		All	0.2-2.5 kg/bed/day	(Africa CDC 2022)
	South Africa	Hazardous	269.12 tonnes/day	(Yadav et al. 2022)
		All	1.2 kg/bed/day	(Singh et al. 2022)
	Egypt	Hazardous	128.54 tonnes/day	(Yadav et al. 2022)
	Nigeria	All	2.5 kg/bed/day	(Singh et al. 2022)
	Ethiopia	All	1.8 kg/bed/day	(Singh et al. 2022)

5. COVID-19 and Circular Economy: Strategies for Medical Waste Management

To counteract the socioeconomic implications of the global epidemic, nations around the world adopted massive stimulus packages as a part of their fiscal policies. The primary purpose of each of these packages was to aid both citizens and industries adversely affected by the COVID-19 outbreak. Moreover, the majority of these packages included several incentives for productive sectors and enterprises. Finally, most of these stimulus packages featured extensive private sector participation.

In this regard, Circular economy could play a crucial role in COVID-19 recovery plans by promoting sustainable growth, economic resilience, and value creation. Before the outbreak, several governments were advancing a circular economy approach prior to the outbreak, recognising the need for a unique economic model that eliminates waste, protects the environment, and conserves resources (Teymourian et al. 2021). Currently, and in light of the threats posed by the global pandemic, governments are required to transform their linear economies with a view to promote employment and equity in the short term and mitigate the long-term environmental risks, including climate change and biodiversity loss (Ellen MacArthur 2020; Tirkolaee et al. 2021). To achieve these goals, policies must be directed towards: a robust economic recovery from the impacts of COVID-19 enabled by CE; promoting public-private partnership in the recovery process; developing incentives that will support a low-carbon, circular economy; and expanding the scope of circular investments (Ellen MacArthur 2020).

Consequently, shifting current linear economies into CE could contribute to minimize the long-term adverse impacts of the global pandemic. Among the opportunities presented by CE in this regard (Ibn-Mohammed et al. 2021):

- CE enhances the productive capacity of the economy, which will minimise the dependency on one nation as the global industrial hub.
- CE shifts production from energy-intensive industries towards environmentally-friendly ones through reliance on renewables, and therefore minimises pollution and GHG emissions.
- CE contributes to job creation in various sectors, including construction, health, food, mobility, etc.

Medical waste poses major environmental and health risks given their contagious, radioactive, hazardous, and toxic nature (Lee et al. 1991). In contrast with municipal waste, the management of medical waste necessitates the use of specific techniques and approaches. In addition, the regulation of medical waste disposal is generally governed by strict legal and institutional framework in most countries. Prior to the outbreak, substantial amounts of medical waste were generated globally, reaching millions of tons each year (Teymourian et al. 2021). COVID-19 has exacerbated this situation through increasing demand on PPE and other medical equipment.

As explained earlier, the conventional methods of managing medical waste include collection, separation, transportation, incineration, decontamination, and disposal (Prata et al. 2020). These procedures are burdened by a number of complexities that affect their efficiency (Windfeld and Brooks 2015). To address these challenges, categorising medical waste based on its material is critical for waste elimination and recycling, which is regarded as the main aim of CE (Kaiser et al. 2001; Prata et al. 2020; Silva et al. 2021). Based on material, medical waste could generally be either glass, fabrics, cotton, plastics, metals, or paper (Wong et al. 1994). Consequently, in order to mitigate some of the risks posed by COVID-19, CE proposes a product design that involves increasing the proportion of recyclable and biodegradable materials in the production of medical equipment and PPE (Napper and Thompson 2019).

Nevertheless, there exists a number of barriers that might restrict the efficiency of CE as a means of eliminating the environmental risks associated with medical waste management. For instance, and given the particular nature of medical equipment, some of its products are not eligible to be produced from recyclable or biodegradable materials. Furthermore, the necessity to minimize health and safety risks associated with medical waste and the need to comply with stringent regulations, are generally prioritised over the environmental benefits of implementing a CE approach in medical waste management (Kane et al. 2018). Despite the limitations stated above, the potential advantages of employing a CE approach in medical waste management are evident in terms of streamlining medical supply chains and minimizing overhead expenses (Ibn-Mohammed et al. 2021).

To highlight the role of CE in medical waste management, studies adopt a broad classification of medical waste into general waste and infectious waste, with general waste constituting a larger proportion than infectious waste (Diaz et al. 2008; Eleyan et al. 2013; Özkan 2013). Due to the large amount of medical waste discarded annually, incineration is the most frequent approach for treating both forms of medical waste; yet, this method poses considerable environmental problems due to the emission of harmful chemicals (Yang et al. 2009; Cobo et al. 2018; Chen et al. 2019). Adoption of CE could aid the transition to an environment-friendly approach of medical waste management through extending the lifespan of medical products and reusing/recycling medical instruments (Cimprich et al. 2019; De Soete et al. 2017). Nonetheless, the precautionary measures undertaken to contain the global pandemic has resulted in an increase in the size of infectious waste, and therefore limiting the potential for reuse and recycling of medical equipment (Peng et al. 2020).

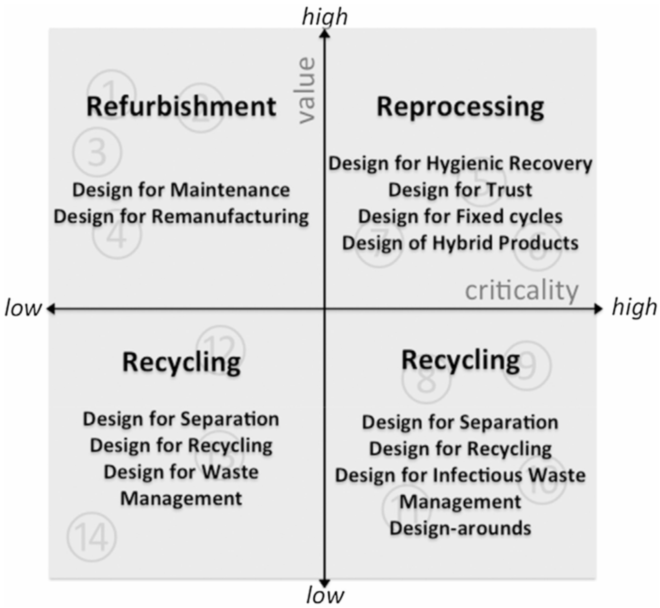
Various studies have analysed the different strategies of CE in managing medical waste (Kane et al. 2018; Voudrias 2018; Teymourian et al. 2021; Cobo et al.2018; Chauhan et al. 2021). These strategies vary between recycling, repair, refurbishment, and reprocessing. Figure 5 outlines the different CE strategies for medical products based on their value and criticality.

The process of recycling medical items involves reconstructing the product into a useable form. Since recycling primarily depends on the product's components, the recycling eligibility of medical products varies (Kane et al. 2018). According to Lee et al. (2002), it is estimated that 20–25 per cent of medical waste consists of recyclable materials. Nevertheless, as mentioned earlier, the existence of infectious waste impedes the potential for recycling, since the strict regulatory framework in most countries necessitates employing specific methods for disposal of contagious waste. According to CE approach, the medical product would be subject to "hygienic obsolescence", because it no longer meets the necessary hygienic criteria for its restoration after use, rendering it obsolete (Kane et al. 2018).

Sterilisation is one type of reprocessing used in the management of medical waste. It aims to address the hygienic obsolescence of medical waste by rendering contagious waste hygienic. Infectious waste is sterilised by being exposed to higher temperatures or chemicals, which helps to separate, recycle, and recover medical waste (Chartier 2014; Hong et al. 2018). One major challenge related to this method is cost and safety considerations, since these procedures are generally costly to conduct in addition to the fact that they require transportation of infectious waste, posing the risk of leakage of infectious waste during the process of transportation (Kane et al. 2018; Wang et al. 2020). Additionally, as some of these products are already designated as single-use products, the effectiveness of this method is highly dependent on the subject product's capacity to endure following the sterilisation process (Rutala and Weber 2008). Incineration is the most inexpensive and therefore the most prevalent method of managing infectious waste (Voudrias 2018).

Maintenance/repair aims at restoring a medical device that has temporarily malfunctioned. It also focuses on the prevention of this malfunction. Durable medical devices constitute the main subject of this procedure. Globally, this method is carried out by professional bio-medical engineers who are qualified to deal with the risks of medical equipment (Enderle and Bronzino 2012). The role of maintenance and repair varies between developed and developing countries. For instance, in Europe and North America, third-party service facilities or device manufacturers handle the maintenance of medical equipment. The market for maintenance of medical equipment is expected to grow from $45.2 billion in 2021 to $74.2 billion by 2026 (Markets and Markets 2021). As the case with sterilisation, cost and safety concerns constitute the key obstacles for this process. It must be noted, however, that in terms of cost, maintenance is less costly as compared with repair, since maintenance is restricted to regular cleaning, inspecting, and replacing particular components of the medical device (Jamshidi et al. 2014).

Figure 5: CE Strategies for Medical Products



Source: (European Environmental Agency 2022; Graulich et al. 2021)

Refurbishment and remanufacturing involve the recovery of medical equipment by the manufacturer for the purposes of redistribution after being ready for use (Chen et al. 2018; Thierry et al. 1995). Refurbishment occurs when a product contains defects or has not been sold on the market. Prior to redistribution, refurbished products must be subject to inspection by the manufacturer to ensure appropriate operation and are therefore defect-free (Thierry et al. 1995). In general, this method involves durable, high-value medical equipment that are essentially reusable. In terms of output quality, refurbishment is different from remanufacturing; Refurbishing may result in a product of lesser quality than the original, whereas remanufacturing aims to bring the product's quality up to par with the original (Ijomah and Childe 2007). Utilizing refurbishment and remanufacturing to prolong the lifespan of high-value medical devices is a standard procedure in the medical industry. It is estimated that the global market for refurbished medical equipment is expected to increase by 11.8% between 2020 and 2025, reaching $21.2 billion in 2025 as compared with $12.1 billion in 2020 (Markets and Markets 2020). The primary contributors to this growth are budget cuts in the medical business, the expansion of e-commerce, and the widespread shift to eco-friendly products (Markets and Markets 2020). One of the key challenges related to this procedure is cost. Since the design specifications of new and refurbished/remanufactured items differ, it remains a challenge for firms to balance the costs of producing new and refurbished/remanufactured products (Boorsma 2016).

In terms of value savings, recycling of waste in general and medical waste in particular is one of the most important strategies of circular economy since recycling contributes to maintaining the value of recycled materials (IGES 2021). Therefore, the raw materials or resources are efficiently utilized instead of being wasted. Recycling results in expanding the life span of products and materials, and consequently maximises their economic value, if executed in a regulated way (IGES 2021)

Implementing circular economy principles results in direct cost savings for hospitals and medical facilities through recycling medical waste or following sterilization procedures to minimize infection, and thereby reduce the quantity of waste (WHO 2019). This view considers that such savings cannot achieve the best benefits except if redirected towards the medical sector in order to reduce the cost of providing healthcare services (WHO 2019)

According to IGES (2021), Recycling of medical waste could generate revenue to offset costs, including costs of medical waste management services and on-site incineration. Based on an assessment conducted in a medical facility in Nepal in 2014, it was estimated that approximately 45% of the total daily medical waste (equivalent to 432 kg/day) could be recycled, with a total monthly sale value 240,000 NPR (or approximately 2,450 USD) (IGES 2021). In 2019, more than 500,000 NPR resulted from annual sales of recyclable medical waste, including more than 100,000 NPR in

December. The total value of sales for the year, including US$890 for December, exceeded $4,500 as of December 2019 (IGES 2021).

One of green economy mechanisms is reprocessing which includes processing of medical devices. In 2018, maintenance and processing companies have saved $470 million in production expenses of hospital devices, which is equivalent to 7100 tons of consumer devices waste. (IGES 2021). As for reprocessing companies in USA, the process saved approximately 4.6 million devics that is equivalent to 935 tons of medical waste (Kane et al. 2018).

The evaluation of the many CE solutions that may be implemented in the management of medical waste reveals a number of obstacles that could compromise the effectiveness of these strategies. Cost considerations remain the main barrier for the majority of methods. The primary concern that emerges is whether recycling, recovering, or reusing the product is more financially feasible than disposing of it (Cong et al. 2017). A cost-benefit analysis must, therefore, be conducted. It must be noted that due to the distinct nature of medical waste, a cost-benefit analysis of recovery must consider the potential cost of health and safety risks associated with its management (Sloan 2007). According to Sloan (2007), cost effectiveness varies across CE strategies applied on medical waste management. Refurbishment and remanufacturing continue to be the most cost-effective choice since they target high-value and durable medical equipment that is, by design, reusable. In contrast, because single-use equipment is not essentially reusable, calculating the cost/benefit of recovery solutions is a difficult procedure. Nevertheless, given the increased cost of production, sterilisation remains a cost-effective alternative for medical facilities. A second challenge is the existence of stringent regulatory framework that governs the management of medical waste in most countries. Such regulations generally prioritise safety considerations when dealing with infectious waste, which would hinder the recovery options in this case.

6. Regulatory Framework of Waste Management in Egypt

Waste management in Egypt is governed by both a legislative and an institutional framework. The legal framework consists of the laws and regulations that govern Egypt's waste management.

The environmental matters in Egypt are regulated by Law No. 4 of 1994, which promulgates the Environment Law.[1] The law is supplemented by its executive regulation issued by the prime ministerial decree No. 338 of 1995. Both the law and its executive regulation establish a mandatory framework for environmental protection and waste management. The law, for instance, establishes the necessary policies, strategies, and programmes for

(1) Full text of the law and its executive regulation is available at https://www.eeaa.gov.eg/en-us/laws/envlaw.aspx

environmental conservation. The law additionally monitors the execution of such policies. The law was subject to amendments of selected provisions by the laws No. 9 of 2009 and 105 of 2015.

In Article 1, the law defines hazardous waste as “Waste of activities and processes or its ashes which retain the properties of hazardous substances and have no subsequent original or alternative uses, like clinical waste from medical treatments or the waste resulting from the manufacture of any pharmaceutical products, drugs, organic solvents, printing fluid, dyes and painting materials” (Ministry of State for Environmental Affairs 1994). Consequently, the law categorizes any waste resulting from medical or pharmaceutical processes as hazardous waste. It does not differentiate between general medical waste and infectious medical waste. In addition, in the context of this law, waste management includes waste disposal, recycling, transportation, or collection (Ministry of State for Environmental Affairs 1994). Waste disposal, therefore, contrasts with waste recycling under the provisions of the law. Waste recycling is restricted to reuse or extraction of waste, including refinement of oil, treatment of soil, and extraction of solid and organic materials. On the other hand, waste disposal incorporates conventional processes of waste management, including treatment, dumping in landfills, incineration, or storage.

Chapter two of the law entitled “Hazardous materials and waste”, which includes articles 29-33, regulates the procedures and strategies for management of hazardous waste. Disposal of hazardous waste in completely prohibited under the provisions of this law. In addition, the establishment of any facilities for the purposes of handling such waste requires a prior authorization from the competent authority (Ministry of State for Environmental Affairs 1994). Additionally, import, entrance, or transit of hazardous waste into or through the Egyptian territory is entirely prohibited. In all circumstances, management and disposal of hazardous waste is conditional by limiting the environmental risks resulting from such processes (Ministry of State for Environmental Affairs 1994). In the event of environmental infractions, the legislation specifies a range of penalties.

The executive regulation of the environment law was issued by the prime ministerial decree No. 338 of 1995. Article 25 of the executive regulation reaffirmed the prohibition against handling hazardous chemicals and wastes without a previous licence from the relevant authorities. The article further outlined the types of hazardous waste as follows (*Executive Regulation of Law No.4 of 1994* 1995):

1. Agricultural hazardous substances and wastes, including pesticides and fertilizers - Ministry of Agriculture.
2. Industrial hazardous waste and materials - Ministry of Industry.

3. Hazardous substances and wastes from hospitals, clinics, medical facilities, pharmaceutical and laboratory facilities, and household insecticides - Ministry of Health.
4. Petroleum hazardous materials and wastes - Ministry of Petroleum.
5. Hazardous materials and wastes emitting radiation - Ministry of Electricity - Atomic Energy Authority.
6. Explosive and flammable hazardous materials and wastes - Ministry of Interior.
7. Other hazardous substances and wastes.

In addition, Article 28 of the executive regulation outlined the norms and procedures governing hazardous waste disposal. It categorises waste management process into four main stages: waste generation, waste collection and storage, waste transportation, and waste treatment. With regards hazardous waste treatment, the regulation differentiates between hazardous waste is subject to reuse/recycle and hazardous waste that cannot be reused or recycled. Treatment of hazardous wastes that are reusable and recyclable is carried out under the following framework (*Executive Regulation of Law No.4 of 1994* 1995):

1. Reuse of some hazardous wastes as fuel for power generation

2. Recovery and reuse of organic solvents in extraction processes.
3. Recycle and reuse of some organic materials from hazardous wastes.
4. Reuse of ferrous and non-ferrous metals and their compounds.
5. Recycle and reuse of some inorganic materials from hazardous wastes.
6. Recovery and rotation of acids.
7. Recovery of materials used to reduce pollution.
8. Recovery of some ingredients of auxiliaries.
9. Recovery and reuse of used oils after refining, taking into account the relationship between environmental and economic returns.

In addition to the environmental protection, Egypt issued Law No.202 of 2020 that promulgates Waste Management Regulation Law. It is considered the first legislation specifically dedicated for comprehensive regulation of waste management in the nation's history. Figure 6 outlines the structure of the Waste Management Regulation Law.

Figure 6: Structure of Waste Management Regulation Law

Source: (Waste Management Regulation Law 2020)

The first part of the law incorporates the general provisions. It distinguishes between different types of waste. The law adopts a broad classification of waste where it is categorised as either hazardous or non-hazardous. It further classifies waste based on its origin into municipal waste, agricultural waste, construction waste, and industrial waste (*Waste Management Regulation Law* 2020). According to the provisions of this law, hazardous waste is "the waste contains organic or inorganic components or compounds that are harmful to human health or the environment due to their physical, chemical or biological characteristics, or because they contain dangerous characteristics such as infectious, flammable, explosive or toxic substances" (*Waste Management Regulation Law* 2020).

With regards waste management, the law indicates that integrated waste management involves the integration of waste management activities, including the process of limiting its generation, reuse, assembly, storage, screening and transfer to the designated sites or facilities, and its treatment, valuation, recycling, and final disposal in an environmentally safe manner. In addition to the conventional methods of waste management, the law recognizes both reuse and recycling as CE strategies. According to the provisions of this law, reuse includes the process of restoring waste for the same purpose as it was previously used. In contrast, recycling is the process by which waste is treated in a way that allows it to be reused for a purpose other than the purpose for which it was originally used (*Waste Management Regulation Law* 2020). In addition, the law outlined a waste management hierarchy in which waste management procedures are placed in a specific order, beginning with the reduction of waste generation rates, followed by reuse, recycle, recovery, treatment, and finally disposal. Lastly, the law introduces a system of green labelling in which producers are awarded a certificate when they design their products in a way that reduces waste generation or facilitates recycling after use. The label is placed on such products to inform the consumer of environmentally friendly products (*Waste Management Regulation Law* 2020).

The law establishes a public authority called "Waste Management Regulatory Authority" (WMRA), which would be in charge of the waste management system nationwide. It shall have public legal personality, have its headquarters in Cairo, and report to the competent minister. The Chairman of the Board of Directors may authorise the establishment of branches or offices for the authority in other governorates. (*Waste Management Regulation Law* 2020).

The law has specified a set of incentives for facilities engaged in waste management. For instance, article 23 stipulates that enterprises and establishments whose primary goal is to conduct integrated waste management activities are eligible for the benefits, guarantees, exemptions, and incentives outlined in Law No. 72 of 2017 on Investment (*Waste Management Regulation Law* 2020). In addition, article 24 indicated that "establishments, companies, and persons authorized to engage in an integrated waste management activity may allocate a percentage not exceeding (10%) of their annual net profits to support and enhance the integrated waste management system; costs and expenses spent by these establishments, companies or authorized persons are deductible in accordance with the provisions of the Income Tax Law promulgated by Law No. 91 of 2005" (*Waste Management Regulation Law* 2020). Finally, the law determines a number of sanctions in case of violation of any of its rules; these sanctions range between imprisonment, fine, or suspension of license or authorization issued by the authority.

The law sets up a stringent system for waste management. It is illegal to engage in any integrated waste management activity involving nonhazardous waste without a prior authorisation from the competent authority. In addition, those in charge of any integrated waste management activity are obligated to take all necessary precautions to avoid any damage to the environment (*Waste Management Regulation Law* 2020). Further strict conditions are required in case of management of hazardous waste. It is forbidden to create or operate facilities engaged in handling or integrated management of hazardous materials or waste without a licence from the competent administrative authority and the authority's consent. The disposal of hazardous materials or waste must conform to the requirements and criteria outlined in the law's executive regulation (*Waste Management Regulation Law* 2020). In addition, all businesses that generate hazardous wastes are required to categorise, collect, and package them, as well as provide the necessary equipment and supplies for separation, collection, transportation, and storage inside the facility. Finally, export, import, transit of hazardous waste is completely prohibited under the provisions of the law (*Waste Management Regulation Law* 2020).

The executive regulation of the Waste Management Regulation Law was issued by the prime ministerial decree No.722 of 2022. The provisions of the executive regulations of the Waste Management Regulation Law, were issued in 56 articles across 6 chapters. It included provisions related to Waste Management Regulatory Authority, its functions, and tasks (*Executive Regulation of Law No.202 of 2020* 2022). The regulation allocated a special section for non-hazardous waste, including municipal waste, demolition and construction waste, agricultural waste, and industrial waste. The regulation also included a chapter on hazardous materials and waste, and provisions for the integrated handling and management of hazardous materials and waste (*Executive Regulation of Law No.202 of 2020* 2022).

The executive regulation defines medical waste as waste generated from healthcare facilities and hospitals affiliated to the Ministry of Health, Ministry of Higher Education, universities in addition to private clinics, veterinary clinics, and laboratories (*Executive Regulation of Law No.202 of 2020* 2022). It elaborated on the treatment and recycling of municipal garbage, agricultural waste, construction and demolition waste, and industrial waste, among other types of nonhazardous waste. Lastly, the rule outlined the procedures and strategies for the treatment and integrated management of hazardous waste, confirming the stringent framework outlined in the Waste Management Regulation Law (*Executive Regulation of Law No.202 of 2020* 2022).

The National Solid Waste Management Programme (NSWMP) is established by the Egyptian Ministry of Environment. The initiative is to assist the Waste Management Regulatory Authority (WMRA) in establishing a sustainable and integrated system for solid waste management in four governorates (Kafr El-Sheikh - Gharbia - Assiut - Qena), in addition to providing the required support to the WMRA (NSWMP 2019). In addition, the program seeks to restructure the waste sector at the national and local levels, including the development of an autonomous central institution to organise the management of the municipal solid waste system and the establishment of waste management units in the selected governorates. (NSWMP 2019). The program is planned to be executed between 2012 and 2022. The program is jointly sponsored with a total budget of €71.9 million by 30% national financial institutions and 70% international institutions. (NSWMP 2019). It further sets the cornerstone to implement integrated waste management system through preparation of codes, manuals, strategies, action plans, and unified law to regulate waste management within Arab Republic of Egypt as follows (SIS 2021):

1. Egyptian codes

   i. Municipal solid waste code: It sets up design principles and implementation conditions of municipal solid waste management system.

   ii. Construction and demolition debris code (recycling): It amends 16 standards for managing construction and demolition debris to support recycling of construction and demolition waste.

2. Manuals

   i. Manuals to process municipal solid waste in case of epidemic outbreak and safety procedures and precautions for employees within the waste management system.

   ii. Manuals to prepare studies on the environmental and social impact of solid waste management projects such as intermediate and recycling plants of waste and sanitary landfills.

   iii. Manuals to close and rehabilitation of random dumps of construction and demolition debris.

In addition to national laws, regulations, and plans, Egypt is a signatory to a number of international environmental protection and waste management treaties and agreements. According to the legal system in Egypt, the ratification of international conventions results in considering their provisions a part of municipal legislations. Among these conventions is The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. The fundamental objective of the Basel Convention is to reduce the threats that hazardous waste poses to the environment and to human health. The Convention is focused on the following main objectives (UNEP 2011):

1. reducing the generation of hazardous waste and enhancing its management systems considering their environmental effects.
2. Prohibiting the transportation of hazardous wastes across borders unless it is executed with environmentally sound methods.
3. Establishing a regulatory framework applicable in situations when movement of hazardous waste across borders is authorised.

With regards the institutional framework of waste management in Egypt, it incorporates government agencies and NGOs concerned mainly with waste management. The Waste Management Regulatory Authority, established under the provision of the Waste Management Regulation Law, is the principal government body that regulates waste management framework in Egypt (WMRA 2021b). Figure 7 illustrates the different functions of WMRA.

Figure 7: Functions of Waste Management Regulatory Authority

Source:(WMRA 2021b)

According to WMRA (2021a), the mission of the authority is to:

1. Regulate and oversee waste management procedures at both national and local scope in order to improve the environmentally safe management service.
2. Build ties between Egypt and other nations and international organisations in the waste industry.
3. Recommend the legal actions necessary to be taken for accession to the international and regional conventions related to waste.

4. Encourage and attract investment in waste collection, transportation, processing, and disposal.

Table 4: Summary of Regulatory Framework of Waste Management in Egypt

Title	Type	Scope
Environmental Protection Law	Legislation	- Environmental protection - Pollution Control - Emissions Reduction - Waste Management
Waste Management Regulation Law	Legislation	- Sustainable Waste Management - Sustainable Financing - Waste Reduction - Recycling/Recovery/Reuse
National Solid Waste Management Programme	Program/Plan	Sustainable and Integrated Solid Waste Management
Waste Management Regulatory Authority	Institution/Public Entity	Sustainable and Integrated Solid Waste Management

Source: (Compiled by authors)

7. COVID-19 and Medical Waste Management in Egypt

7.1 Impact of COVID-19 on Medical Waste Generation in Egypt

As the case with all countries worldwide, COVID-19 has resulted in significant impacts on medical waste management in Egypt. When analysing such impacts, it is important to distinguish between two types of medical waste: medical waste originating from healthcare facilities and residential medical waste in the form of disposed PPE. This distinction is vital given the fact that the predominant methods of waste disposal in Egypt lacks proper safety, since they generally take place through discarding wastes in exposed and uncontrolled locations with the absence of any health or environmental precautions (Mostafa et al. 2021). In that case, even residential medical waste could be regarded as infectious as it may be disposed by infected residents.

The hazardous medical waste sector in Egypt has witnessed a noticeable increase in daily quantities since the emergence of confirmed cases of COVID-19 (Mostafa et al. 2021; Gawish 2020; Torieh et al. 2020; El-Ramady et al. 2021). Medical waste produced from quarantine hospitals, consisting of gloves, masks, protective jackets, and used medical syringes, is disposed where doctors and nurses, after dealing with infected cases, replace them with new sterile ones, which represents a challenge for managing such waste as it might contribute to the spread of the epidemic (Gawish 2020). The precautionary measures adopted to contain the pandemic have brought about a substantial growth in the use of single-use PPE, including masks and gloves, in addition to sanitizers and disinfectants (Noureldin 2020).

The average volume of medical waste is estimated based on the daily generation rate for each bed or the daily generation rate for each healthcare facility. According to these estimates, the average daily volume of medical waste for all Egyptian healthcare facilities is 300 tons per day (Gawish 2020; Egypt Independent 2020). According to Singh et al. (2022) and Yadav et al. (2022), the amount of medical waste generated during the outbreak was estimated to be 1.2 kg/bed/day, while hazardous medical waste was estimated to be 128.54 tonnes/day. Finally, based on the results of the study conducted by El-Ramady et al. (2021), COVID-19 prompted a significant increase in healthcare waste generation from 70 to 300 tons on daily basis. Finally, for the purpose of analysing the distribution of medical waste generation between urban and rural areas in Egypt, Abouzid et al. (2022) concluded that medical waste generated in urban areas increased substantially as compared with rural areas.

In addition, and for the purpose of estimating the amount of single-use face masks generated daily, the calculation is based on the overall population of each country, daily face mask consumption per person, and an assumed percentage of urban residents who tolerate the use of face masks (Nzediegwu and Chang 2020). According to Benson et al. (2021), the average number of single-use face mask disposed daily in Egypt was estimated to be 30,805,013 face masks, based on an overall population reaching 102,342,235, 1 face mask used per capita daily, and 70% face mask acceptance among urban population. Table 5 summarises medical waste generation resulted from COVID-19 based on existing literature.

Table 5: Medical Waste Generation in Egypt During COVID-19

Type of Medical Waste	Amount/Measurement	Reference
General	300 tons/day	(Gawish 2020; El-Ramady et al. 2021)
General	1.2 kg/bed/day	(Singh et al. 2022)
Hazardous	128.54 tonnes/day	(Yadav et al. 2022)
Single-use Face Masks	30,805,013 face masks	(Benson et al. 2021)

7.2 Integrated Waste Management Strategies in Egypt

The Ministry of Environment has undertaken a number of programs and strategies during 2021 to start the actual implementation of the integrated waste management system in cooperation with all concerned stakeholders, in addition to some interventions in cooperation with the governorates to raise the efficiency of the hygiene system, and to ensure facilitating the stages of waste handling until safe disposal. Among these programs and strategies (SIS 2021):

1. The first program: Supporting the infrastructure of the waste management system in the various governorates through:

i. The establishment of sanitary landfills, intermediate stations, and recycling plants.

- Currently, about 80% of the infrastructure of the waste system has been implemented, as 10 sanitary landfills, 13 fixed intermediate stations, and 11 mobile stations were delivered as a first stage.

2. The second program: Corporate support and social engagement through:

i. Waste-to-energy projects, including:

- Preparation of a manual for waste-to-energy projects and qualification submissions for companies wishing to work and invest in this industry.
- Study the initial layout of the roadmap and the available investments within the geographic distribution all over the republic.
- Selection of Egyptian companies to be funded by Egyptian development banks with a total investment of $340-400 million.

ii. Integration of unofficial waste sector, including:

- 4200 individuals all over the country have registered their data on the website as employees in waste recycling sector as part of the cooperation protocol between the Ministry of

Environment and Ministry of Social Solidarity to officially register non-regular employees in the system.

- The Ministry of Environment (represented by WMRA) prepared a draft for (4) job titles in waste management industry: collector, sorter, recycler, and disposer within the waste management system.

3. The third program: Legislative support through establishing the legal and institutional framework that regulates integrated waste management, including promulgating Waste Management Regulation Law and its executive regulation in addition to establish Waste Management Regulatory Authority.

With regards waste-to-energy projects, and by using 4.2 Mt of solid waste, the government intends to produce 300 MW of electricity from waste by 2025 (Salem 2020; Egypt Today 2021). Prime Ministerial Decree No.41 of 2019 allowed a feed-in tariff of 140 piasters per kilowatt for electricity produced by waste-to-energy facilities employing municipal solid waste and landfill-extracted biogas (Egypt Today 2021). On the basis of this programme, eight companies out of 93 applicants were selected to establish waste-to-energy plants in eight governorates with investments totalling USD385 million. (Egypt Today 2021).

In accordance with NSWMP, Infrastructure facilities established to raise the efficiency of waste management system include

1. Implementation of seven (7) intermediate stations in the governorates of Gharbia, Qena and Assiut by contracting with the Arab Organization for Industrialization, at a financial cost of EGP94.5 million, in Abu Tig, Abnoub, Manfalut, Zefta, and Abu Tisht districts.
2. The completion of the implementation of two (2) intermediate stations in Dayrout and Abu Tig districts.
3. Completing the implementation of one (1) intermediate station in Qena Governorate, in Abu Tisht district.
4. Lifting waste piles from seven (7) random dump sites in the governorates of Gharbia and Kafr El-Sheikh, with a total of 30.5 million pounds.
5. Rehabilitation and upgrading of five (5) waste treatment plants in three governorates: Kafr El-Sheikh, Qena, and Al Gharbia at a financial cost of EGP24.2 million.

In addition to the aforementioned efforts, and with regards hazardous materials and waste, the first draft of the lists of hazardous materials and waste was discussed in preparation for issuance and establishing the first phase of the information system for hazardous materials and waste, which involves registration to facilitate procedures for importers and exporters (SIS 2021).

7.3 Current Practices of Medical Waste Management in Response to COVID-19

In Egypt, medical waste is treated using incineration in addition to chemical and steam sterilisation (Shouman et al. 2013). As the case with most developing countries, the traditional method of disposing of medical waste is incineration due to the limitations of expanding waste recycling, disposal, and storage capacities (El-Ramady et al. 2021; Singh et al. 2022; Shouman et al. 2013). Given the corresponding health and environmental risks, incineration is not regarded as the optimal method for treating medical waste (Chisholm et al. 2021). Globally, countries have enacted stringent regulations to limit waste management emissions. In addition, ash resulting from incineration of medical waste is considered hazardous waste, necessitating its safe removal to prevent airborne contamination (El-Ramady et al. 2021). Therefore, incineration is regarded as a complex and costly method for management of medical waste (El-Ramady et al. 2021; Shouman et al. 2013; Heidari et al. 2019).

This was confirmed based on the results of the study conducted by Abd El-Salam (2010), which examined the different methods of medical waste management in a random sample of hospitals in Al-Buhayrah Governorate. The study analysed the different stages of medical waste management, including collection, storage, transportation, treatment, and final disposal. It concluded that incineration was the prevalent method for handling solid medical waste in the studied medical facilities. The study further deduced that the inefficiency of the process of medical waste management in the studied hospitals was mainly attributed to inadequacies in all stages of waste management, including collection, segregation, and storage in addition to the lack of sufficient financial and human resources.

Prior to the outbreak of the global pandemic, MOE has undertaken the following procedures to enhance the efficiency of medical waste management (Ministry of Environment 2019):

1. The adoption of proper management of the hazardous medical waste through source segregation in accordance with the type of medical waste and the method of treatment to ensure compliance with environmental requirements.
2. The rehabilitation of selected healthcare facilities to implement a proper management system for medical waste.
3. Installation of a central treatment plant for hazardous medical waste using shredding and sterilisation technologies in selected healthcare facilities.
4. Issuance of the final draft of the general policies for medical waste management.

5. Preparing qualified personnel in the field of sound and sustainable management of hazardous medical waste and encouraging private sector participation in cooperation with the Ministry of Health.

In response to the impacts caused by COVID-19 on waste generation and management, especially medical waste, the Egyptian government established a nationwide strategy that involves the collaboration of a number of relevant ministries, including Ministry of Environment (MOE), Ministry of Health (MOH), and Ministry of Higher Education and Scientific Research (MOHE) (Torieh et al. 2020). The core objectives of this strategy include developing a mechanism for proper and safe handling of solid and medical waste, assessing the environmental status in densely-populated areas, and raising environmental awareness (Egypt Today 2020). Additionally, and considering the growth in medical waste generation, the MOH established guidelines and processes to restrict the contamination of municipal waste through separation of medical waste from municipal waste (Torieh et al. 2020). The Ministry of Health has also established a training program that targeted 68 employees in 16 governorates to promote sustainable management of medical waste (Egypt Today 2020). The proposal involves collaborating with the Ministry of Tourism to efficiently manage waste in hotels designated for quarantine (Torieh et al. 2020; Egypt Today 2020). Finally, The ministry has examined the medical waste management systems in 1,537 medical institutions in order to monitor safe handling of such waste, and the procedure was being monitored by designated committees in collaboration with health directorates and university hospitals (Egypt Today 2020).

COVID-19 poses a challenge for waste management, especially the recycling sector. According to work regulations and guidelines during the outbreak, employees and workers who suffer from pre-existing medical conditions were permitted to have a paid sick leave. Consequently, recycling plants operated with less than half of its workforce, which would adversely affect the efficiency of such facilities (Mostafa et al. 2021). Consequently, the recycling sector had been adversely affected by both the increased amount of medical waste and reduced number of labour, which might exacerbate the levels of infection due to the reduced recycling capacity as compared with the amount of healthcare waste generated (El-Ramady et al. 2021).

8. Prospects for Circular Economy in Egypt

Transition to circular economy is not explicitly mentioned in national legislations and policies. However, the Environment Law and the Waste Management Regulation Law indicated, in some of their provisions, a number of CE strategies. In addition, the Sustainable Development Strategy 2030 (SDS), the Sustainable and Green Growth Strategy, the National Action Plan for Sustainable Consumption and Production (SCP), and the National Solid Waste Management Program (NSWMP) are examples of national plans and policies that assist in the adoption of the concept of CE and its strategies (Maamoun 2021; Mahmoud et al. 2020).

As explained earlier, the main aim of Waste Management Regulation Law is to establish a framework for safe and sustainable management and disposal of various types of waste in Egypt, including municipal, agricultural, industrial, and medical waste (*Waste Management Regulation Law* 2020). The major strategies proposed by the law to achieve sustainable waste management include waste reduction, recycling, recovery, and reuse. The law further offers a number of financial incentives to encourage private sector participation in the area of waste management.

In addition, the three main pillars of sustainable development contribute to the transition towards circularity in industry, agriculture, and waste management. Based on the concept of economic sustainability, CE provides a potential for the industrial sector through socially-responsible investments and efficient use of energy (SDS 2030 Egypt 2020). Furthermore, environmental sustainability entails resource conservation, which is the core objective of CE (SDS 2030 Egypt 2020).

The key objective of Egypt's SCP is to promote sustainability in both production and consumption in selected sectors, including water, agriculture, energy, and waste management (Ministry of Environment 2016). The main mechanisms of achieving this objective include promoting the optimum utilisation of natural resources such as water and energy; fostering sustainable agriculture practices; and improving waste management through the application of 3R approach (Ministry of Environment 2016). These mechanisms would eventually result in poverty alleviation through a further equitable distribution of income, environmental conservation, and economic welfare (Maamoun 2021; Schröder 2020). Table 6 outlines the framework of CE strategies in Egypt.

In addition to the legislations, regulations, policies, and plans that promote the implementation of CE strategies in Egypt, there exists a number of initiatives and programs that support CE mechanisms. Table 7 lists a number of CE initiatives and programs in Egypt.

Table 6: Framework of CE in Egypt

Document	Type	Scope	CE Strategies	Reference
Waste Management Regulation Law	Legislation	Waste Management	Sustainable Waste Management and Financing	(Waste Management Regulation Law 2020)
Egypt Sustainable Development Strategy 2030	Strategy	Industry, Agriculture, and Waste Management	Resource conservation, Recycling, Reuse, Recovery	(SDS 2030 Egypt 2020)
National Action Plan for Sustainable Consumption and Production	Plan	Water, Agriculture, Energy, and Waste Management	Sustainable Agriculture, Efficient Use of Resources, and Sustainable Waste Management	(Ministry of Environment 2016)

Table 7: Selected CE Initiatives & Programs in Egypt

Title	Type	Objective
Tagaddod	Private	Treatment and refinement of waste oils, cooking oils, and fats.
Bariq	Private	Plastic recycling
Imkan	Public/International	Entrepreneurship support programmes in agro-industry, renewable energy and waste management.
IEE	Public/International	capacity building and technical assistance in industrial energy efficiency.
E-tadweer	Public/Private	E-waste recycling industry.
Switch MED	Public/International	Training and development programs on resource efficiency and resource savings.
Better Cotton	Public/International	Sustainable agriculture and sustainable cotton production.

Source: (Compiled by authors)

The adoption of CE strategies in Egypt offers a variety of economic, environmental, and social benefits (Justenhoven and de Lange-Snijders 2019; Mahmoud et al. 2020; Murray, Skene, and Haynes 2017; Ngan et al. 2019; Preston, Lehne, and Wellesley 2019; Schröder 2020).

From an economic perspective, the implementation of CE promotes efficient use of resources, maximise savings in production costs, expansion of investments across various sectors, and boosting export performance and competitiveness (Justenhoven and de Lange-Snijders 2019; Mahmoud et al. 2020; Murray et al. 2017; Schröder 2020). It was estimated that the shift to circularity could result in GDP growth rate of 1.0% over business as usual (+€5.2 billion), and a growth in the country exports by €212 million (Mahmoud et al. 2020; Roberts and Abdelaty 2021).

In terms of environmental gains, CE is regarded as a tool for climate change mitigation through limiting GHG emissions from various sectors including energy, agriculture, and waste in addition to other energy-intensive industries such as steel and fertilizers (Maamoun 2021; Ngan et al. 2019). Furthermore, adoption of CE mechanisms in the industry sector results in energy savings by up to 23%-40% (Maamoun 2021).

Finally, the social gains inferred from transition towards CE include better health conditions resulting from reduced pollution, and therefore, enhanced air quality. Circularity further contributes to job creation in various sectors, including recycling, waste management, agriculture, and energy (Mahmoud et al. 2020; Ngan et al. 2019; Preston et al. 2019; Roberts and Abdelaty 2021). The shift towards circularity is projected to increase employment by 0.3% through adding 101,000 jobs in the aforementioned sectors

(Mahmoud et al. 2020). Table 8 summarises the potential benefits of transition to CE in Egypt.

Table 8: Potential Benefits of CE in Egypt

Dimension	Benefits	Reference
Economic	- GDP growth - Improved balance of trade - Efficient use and allocation of resources - Savings in cost of production	(Justenhoven and de Lange-Snijders 2019; Mahmoud et al. 2020; Murray et al. 2017; Schröder 2020)
Environmental	- Reductions in GHG emissions - Reduced pollution - Better air quality - Energy savings	(Maamoun 2021; Ngan et al. 2019)
Social	- Improved human health - Job creation	(Mahmoud et al. 2020; Ngan et al. 2019; Preston et al. 2019; Roberts and Abdelaty 2021)

9. Results and Discussion

Based on the existing literature, the outbreak of the global pandemic has led to an increased demand for medical services, and therefore contributed to a significant increase in medical waste on global basis. The precautionary measures, as advised by WHO, to contain infections involved social distancing, using facemasks, sanitizers, and personal protective equipment (PPE), have resulted in substantial consumption and disposal of medical supplies and equipment. The situation was exacerbated by disruptions in the global supply chains of PPE and medical supplies; these shortages were attributed to increased demand, stockpiling, and panic buying. This posed various challenges to the waste management systems given the environmental and health risks of such waste.

Circular economy represents a potential policy approach to deal with the impacts of the global pandemic. CE could contribute to enhance the resilience of socio-economic systems to the long-term adverse impacts of the pandemic, and therefore could increase economic sustainability. By encouraging sustainable growth, economic resilience, and value creation, CE could, in this regard, play a significant role in COVID-19 recovery plans.

In the area of medical waste management, CE becomes of a particular significance. CE could aid the transition to an environment-friendly approach of medical waste management through extending the lifespan of medical products and reusing/recycling medical instruments considering the environmental risks linked with the traditional methods of medical waste management. As a result, in order to reduce some of the risks associated with COVID-19, CE suggests a product design that involves using more recyclable and biodegradable materials in the manufacturing of medical equipment and PPE.

CE strategies applicable in medical waste management include recycling, repair, refurbishment, and reprocessing. These strategies vary in their efficiency and cost regarding each type of medical waste treated. Refurbishment and remanufacturing remain the most economical options because they focus on high-value, durable, and reusable medical equipment.

A number of challenges that could undermine the efficiency of these strategies are revealed by the evaluation of the various CE solutions that could be used to manage medical waste. For the majority of methods, cost issues continue to be the most significant obstacle. In addition to cost considerations, priority is generally given to minimising health and safety risks associated with medical waste and adhering to strict regulations over the environmental benefits of implementing a CE approach in medical waste management.

As the case with most countries, there exists a stringent regulatory system for waste management in Egypt. The regulatory system of waste management incorporates legislations, regulations, policies, programs, and institutions. In addition to the Environmental Protection Law, the country promulgated the Waste Management Regulation Law as a comprehensive framework for waste management. According to the law, integrated waste management refers to the integration of waste management processes, such as limiting waste generation, reuse, assembly, storage, screening, and transfer to the designated sites or facilities, as well as treating, valuing, recycling, and disposing of waste using methods that safeguards the environment. In addition to typical waste management techniques, the law acknowledges reuse and recycling as CE measures. The law created a public entity known as the "Waste Management Regulatory Authority" (WMRA), which would oversee the nation's waste management system.

Since the emergence of confirmed cases of COVID-19, the volume of hazardous medical waste generated daily in Egypt has increased noticeably. A significant proportion of infectious medical waste is generated by quarantine hospitals. Furthermore, in addition to sanitizers and disinfectants, the pandemic containment measures have resulted in a significant increase in the use of single-use PPE, including as masks and gloves.

In addition to chemical and steam sterilisation, incineration is a method of manage medical waste in Egypt. Due to the limitations of expanding waste recycling, disposal, and storage capacities, incineration is the conventional method for disposing of medical waste. In response to the effects of COVID-19 on waste generation and management, particularly medical waste, the Egyptian government has developed a national policy aimed at establishing a framework for the proper and secure management of solid and medical waste.

After reviewing the current practices of medical waste management in Egypt, we conclude that COVID-19 has resulted in a number of challenges for medical waste management. Despite the existence of a sufficient regulatory framework, there still exists a number of financial and institutional restrictions. Alrawi et al. (2021) indicated that the challenges caused by COVID-19 for medical waste management in developing countries, including Egypt, are: an increase in the volume of infectious waste resulting from the pandemic; partial suspension of medical waste management services; inadequate on-site treatment of medical waste; and improper storage, handling, and removal of medical waste. COVID-19 further restricts the adoption of CE strategies in medical waste management since the increase in the volume of infectious waste limits the possibilities of recycling given the safety and health risks (Alrawi et al. 2021).

In Egypt, selected legislations, strategies, plans, and initiatives assist in the transition to CE, among these are Waste Management Regulation Law, Sustainable Development Strategy, the National Action Plan for Sustainable Consumption and Production, and the National Solid Waste Management Program.

The shift towards CE strategies in Egypt results in different economic, environmental, and social benefits. The economic benefits of transition to CE are visible in GDP growth, improving balance of trade, and reduction in cost of production. The environmental benefits include improving air quality as a result of limiting pollution and reduction of GHG emissions. Finally, among the social benefits incurred from adoption of CE are improved human health and job creation.

10. Conclusion

The COVID-19 outbreak has significantly increased global, regional, and local medical waste generation. Given the risks posed by medical waste to the environment and human health, sustainable management and disposal of medical waste constitutes a considerable challenge, especially for developing countries, including Egypt, as the quantity of medical waste significantly outpaces the waste management capacities. This study reviewed the impact of COVID-19 on global medical waste management and its interplay with CE with a special focus on Egypt as a case study. It further analysed the role of CE approach in mitigating the risks of COVID-19 on medical waste management. CE could aid the transition to an environment-friendly approach of medical waste management through extending the lifespan of medical products and reusing/recycling medical instruments considering the environmental risks linked with the traditional methods of medical waste management. In Egypt COVID-19 has resulted in a number of challenges for medical waste management. Despite the existence of a sufficient regulatory framework, there still exists a number of financial and institutional restrictions. The shift towards CE strategies in Egypt results in different economic, environmental, and social benefits. Resource-efficient activities and prospects for cost savings, import substitution, and emissions reduction are hindered by access to finance and cost considerations involved with some circular economy strategies. Additionally, social measures must be adopted to guarantee an inclusive shift towards a circular economy approach. In order to eliminate long term unemployment among workers employed in areas impacted by the shift towards circularity, job creation in sectors that support CE in addition to the necessary vocational training would be required.

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