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Review

To what extent do waste management strategies need adaptation to post-COVID-19?

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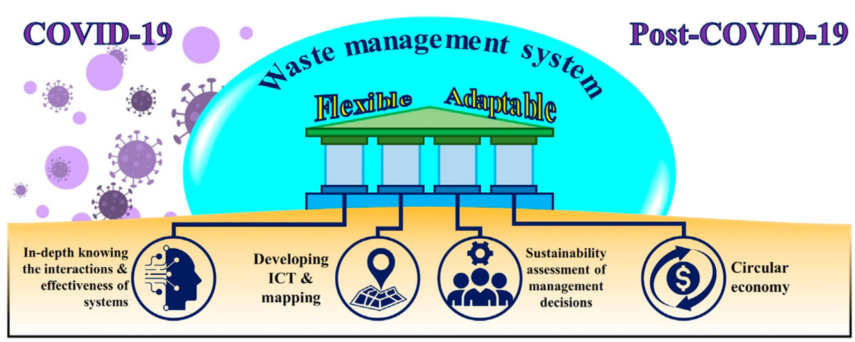
HIGHLIGHTS

- The COVID-19 impulse intensity depends on the epidemic duration and system adaptation.
- Pandemic outbreaks can threaten prioritization in the waste management hierarchy.
- Key pillars are enumerated for flexibility and adaptability of waste management.
- The circular economy is a basic long-term strategy for the survival of recycling.

GRAPHICAL ABSTRACT



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ABSTRACT

The world has been grappling with the crisis of the COVID-19 pandemic for more than a year. Various sectors have been affected by COVID-19 and its consequences. The waste management system is one of the sectors affected by such unpredictable pandemics. The experience of COVID-19 proved that adaptability to such pandemics and the post-pandemic era had become a necessity in waste management systems and this requires an accurate understanding of the challenges that have been arising. The accurate information and data from most countries severely affected by the pandemic are not still available to identify the key challenges during and post-COVID-19. The documented evidence from literature has been collected, and the attempt has been made to summarize the rising challenges and the lessons learned. This review covers all raised challenges concerning the various aspects of the waste management system from generation to final disposal (i.e., generation, storage, collection, transportation, processing, and burial of waste). The necessities and opportunities are recognized for increasing flexibility and adaptability in waste management systems. The four basic pillars are enumerated to adapt the waste management system to the COVID-19 pandemic and post-COVID-19 conditions. Striving to support and implement a circular economy is one of its basic strategies.

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Contents

1. Introduction

The COVID-19 pandemic emerged in 2019; since then, it has affected a plethora of countries worldwide and is still spreading in some countries at the time of writing this paper (WHO, 2021). This untimely period can be regarded as a warning to organizational and managemental systems in different societies, highlighting the need to consider human relationships and their interactions with other environments. Considering the lessons we have learned from this transforming period, it is evident that adaptability to COVID-19 and post-COVID-19 seems essential, creating a shifting paradigm.

The COVID-19 outbreak has brought about serious crises in various sectors, including but not limited to the economy (Aktar et al., 2021), healthcare (Suresh et al., 2022), financial markets (Zhou et al., 2021), businesses (Filimonau, 2020; Neumeyer et al., 2020), supply and demand chains (Aktar et al., 2021; IEA, 2020a). It has been reportedly shown that people's consumption patterns have begun to change during this period (Ikiz et al., 2021; Qian et al., 2020), and more importantly, the trend of waste generation has experienced different patterns (Benson et al., 2021; Filho et al., 2021). The sudden changes in waste generation, if not properly tackled sophisticated actions, can threaten the ecosphere and further endanger public health (Das et al., 2021). The following question arises: what are the challenges the waste management systems face in the COVID-19 era and beyond? The challenges are different from natural disasters (Brown et al., 2011; Zhang et al., 2019) and need to be dealt with in a long-term perspective (Tsukiji et al., 2020). Accurate identification of challenges, to which we are facing now can help revise waste management strategies to be listed on the future agenda. The proposed strategies should be able to prepare the system for rapid adaptation to any pandemics such as COVID-19 and especially in the post-pandemic era. The necessities suggested by World Health Organization and government health agencies should not be overlooked.

Since the start of the COVID-19 outbreak, a large number of scientific reports and papers have been published by scientific communities, where challenges of waste management strategies have been identified from various aspects, based on which possible solutions have been discussed. Fig. 1 shows the classification of 299 documents, indexed at the time of drafting the present paper in Scopus or Clarivate related to “COVID-19” and “waste”. In total, 62% of the documents were descriptive, reviewed and case studies. These documents did not provide comprehensive quantitative information on the flow of waste and its composition in the COVID-19 era. A considerable fraction of these documents has assessed the status of waste generation in particular regions in the form of reports. Some have been conducted via implanting online questionnaires to take specific case studies into account. Some have globally described and reviewed the challenges of managerial strategies by considering only one particular waste management stage or focusing on different aspects of managing a specific waste

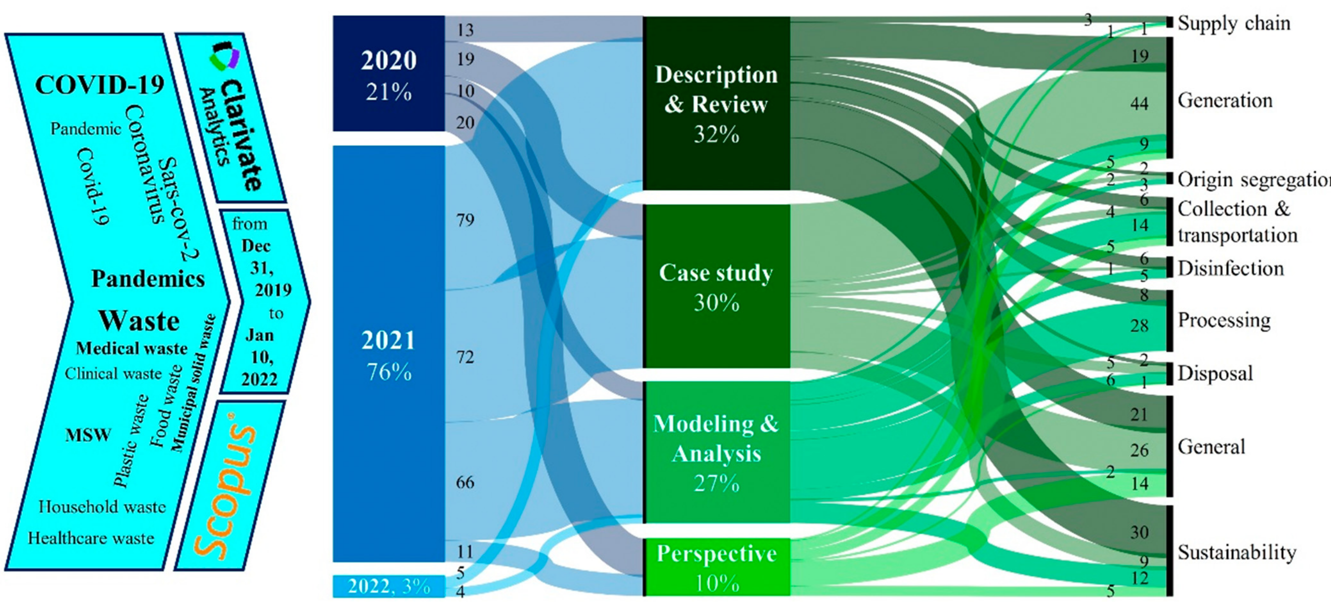

Fig. 1. Search for keywords by categorizing published scientific documents in the databases based on the subject area.

composition. After medical waste (MW), plastic waste has attracted the most attention of researchers. Patrício Silva et al. (2021) attempted to predict the threats of the plastic waste boom caused by changes in consumption patterns and scrutinize the potential challenges during and after the pandemic era. They have suggested creating direct links between industry, policy, and research to minimize the effects of plastic waste on the ecosystem. In a similar study, Vanapalli et al. (2021) expressed that investment in circular technologies such as recycling is key to dealing with a potential plastic waste crisis, and delays in building social desire and participation as a hindrance to long-term goals. In another study conducted by Kulkarni and Anantharama (2020), various aspects of municipal solid waste (MSW) management were investigated. They presented the challenges and consequences of prolonged epidemics and proposed alternative approaches for treating and disposing of MSW. The possibility of unexpected fluctuations in the composition and quantity of wastes was also investigated by some researchers (Sharma et al., 2020). The viewpoints were important, hence later discussed in another short survey conducted by Mohammad et al. (2021). In one perspective paper, Neumeyer et al. (2020) presented the entrepreneurial waste management challenges imposed by COVID-19. Generally, about 10% of these documents briefly presented the perspectives of waste management in the form of notes, short surveys, or letters. As shown in Figs. 1, 56% of them modelled advanced processing and disinfection technologies or analysed technology selection based on sustainability. Fan et al. (2021) updated the indirect impacts on waste management, while Zhou et al. (2021) addressed the COVID-19 influences on the waste-to-material and energy conversion industries. The health-care waste challenges were also among the topics that provoked researchers' interest (Yang et al., 2021). Among the studies conducted to date, a few had also focused on narrow aspects of the challenges arising within some particular regions such as Toronto (Ikiz et al., 2021) and Regina (Richter et al., 2021a) in Canada, Isfahan (Zand and Heir, 2021a) and Tehran (Zand and Heir, 2020) in Iran.

Due to the diversity of technical and policy aspects that have been taken into account so far, there is an urgent need for a critical review of the conducted studies to summarise the current challenges of the waste management system during and after the COVID-19 pandemic. There is no similar review paper to the best of our knowledge, and this study will be the first attempt in this context. The present study has attempted to look at the waste management systems from different points of view and highlighted the technical and scientific challenges in identifying the research gaps and future roadmaps for such adaptations. It also recognizes the necessities and compromises with the COVID-19 and post-COVID-19 era in waste management strategies and offers approaches to impact management practices positively. The structure of this review paper is as follows: Section 2 presents the challenges of the waste management system in the COVID-19 era. These challenges cover the whole waste management system from generation to the final disposal. The impacts of waste management systems will also be discussed, considering the environmental, economic, and energy (3E) aspects during and post-COVID-19 era. Section 3 highlights the necessities of breaking virus transmission lines within waste management systems, and suggestions will be made for proper adaptation to pandemic conditions. Section 4 has attempted to provide new insight into waste management systems during and post-COVID-19.

2. Challenges in the waste management system

Waste management, an integral part of urban management and any human society, is the regular and systematic control of waste flows from production to the final disposal, including generation, collection, storage, transportation, processing, and disposal (Abdoli, 1993). waste management approaches should be consistent with the nature of communities and urban management programs. The management systems in use have evolved over the centuries. The most basic and optimal methods are used in waste management by observing public health, economic, social, technical, aesthetic, and environmental considerations (Brunner and Rechberger, 2015). In the COVID-19 era, environmental health awareness has become more prominent since waste disposal without proper treatment would increase the widespread outbreak probability of infection (Belhadi et al., 2020). In the following sub-chapters, those challenges introduced in different scientific reports are separately discussed in detail.

2.1. Generation and composition of waste

Waste generation functions urbanization, economic development, and population growth (Rajaeifar et al., 2017). As human communities become more populous and prosperous, the standard of living increases while delivering more products and services to citizens (Aghbashlo et al., 2019b). This is followed by more waste generation (Khoshnevisan et al., 2020) and increased the necessity for developing proper waste management systems to secure waste disposal (Aghbashlo et al., 2019a). The wastes can be classified based on the different criteria: physical state, main applications, composition, physicochemical properties, biodegradability, origin, and safety (Edalatpour et al., 2018). Fig. 2 has classified waste streams based on their type and origin (Schiffer et al., 2016) and represents their global

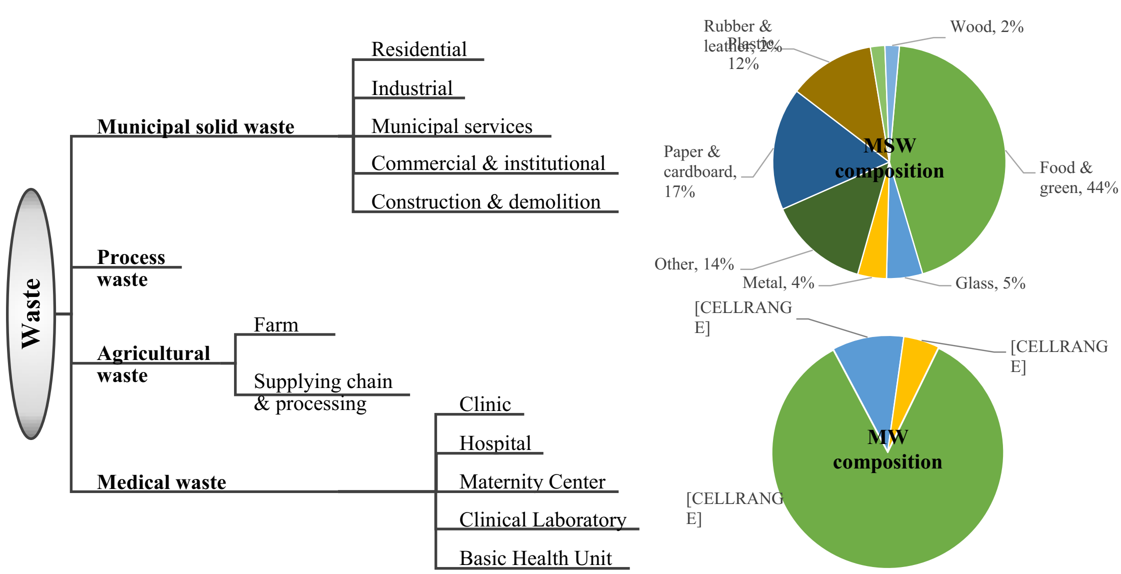

Fig. 2. Waste classification (based on origin and type) and the global average of their composition percentage (before COVID-19) (Data source: Kaza et al., 2018; Schiffer et al., 2016; Tsukiji et al., 2020).

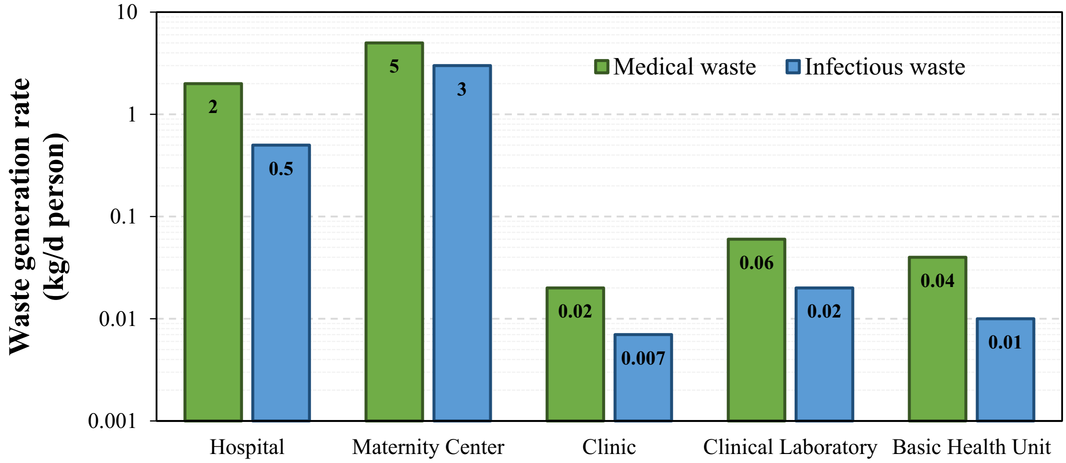

Fig. 3. Average waste generation rates of medical and infectious by type of facility on a logarithmic scale (before COVID-19) (Data source: Tsukiji et al., 2020).

average composition (Kaza et al., 2018; Tsukiji et al., 2020). Process wastes originating from large industries and mines include scrap materials and tools (i.e., all equipment and machines in large industries and mines), non-standard products, slag and tailings, topsoil, waste rock, wastewater, and processing chemicals. Regarding agricultural wastes (AW), the Food and Agriculture Organization of the United Nations (FAO) has made a valuable effort to compile a sophisticated database by collecting data from countries, case studies, assessment models, and literature (FAO, 2021). Despite all the efforts made, it is almost impossible to have precise information over the exact amount of AW production in farms, supply chains, and processing facilities due to their wide range composition and regional diversity (Naughton, 2020).

As shown in Fig. 2, "Food and Green Waste" compose the largest proportion of MSW in various countries. The global average of recyclable materials (i.e., plastic, paper and cardboard, metal, and glass) accounts for 38% of the total MSW. It would be up to 50% for high-income developed countries such as North America, with the highest urbanization rates and average per capita MSW generation (i.e., 2.21 kg/d). The strict policies over plastic material consumption and consequently plastic waste generation, implemented in developed countries, could successfully decrease plastic waste fraction in the MSW. Paper waste still constitutes a high proportion of MSW (up to 25%) (Kaza et al., 2018). Plastic and paper often make up more than half of MW (UNEP, 2021). It has been reportedly shown that 15% and 85% of MW generated in different health-care facilities are hazardous and non-hazardous, respectively. The main hazardous waste is infectious waste (about 10% of the MW generation). Other hazardous waste includes pathological, pharmaceutical, genotoxic, chemical, radioactive waste and sharps. Fig. 3 illustrates the global average generation rate of medical and infectious wastes in various health-care facilities per person accepted or hospitalized on a semi-logarithmic clustered column chart (Tsukiji et al., 2020).

COVID-19 is now a suddenly applied external excitation on the body of the waste management system, which in this paper is interpreted as impulse; News and reports have shown that this impulse has affected the generation and composition of waste streams. This effect has not been hidden from the view of Vu et al. (2021a, 2021b). They modelled the waste generation and disposal rates during the early months of the COVID-19 outbreak in Regina. Nguyen et al. (2021) also affirmed the increase in hazardous waste generation and the predominance of plastic and paper weight percentages in MW under the COVID-19 impulse. The intensity of this impulse depends on the pandemic duration and the system's adaptation. An accurate recognition of the impulse impact is necessary to adapt the system. These impacts are indicated as new challenges of the COVID-19 era. Table 1 lists the impacts and challenges associated with waste generation and composition.

Access to real-world data collected from case studies during and post-COVID-19 is still limited, hindering global analysis of waste generation status in the COVID-19 era. This problem is also a barrier to using modeling techniques normally developed based on observed big datasets. The information presented in Table 1 can be referred to as a basis for a better understanding of changes that may occur in the amount and composition of various waste streams during this period, e.g., changes in waste generation behaviours and habits caused by economic and health crisis as well as lockdown (as a strategy to control pandemic outbreak) (Naughton, 2020; Ouhsine et al., 2020). Certainly, changes in waste generation habits can be moderated by training (Cosgrove et al., 2021; Ikiz et al., 2021). Among the key influencing factors, the lockdown has been introduced as one of the most important reasons which influenced the generation rate and composition of urban wastes (Filho et al., 2021; Haque et al., 2021b). Also, unlocking has the same effect with a longer response time (Cai et al., 2021). The terms and conditions of the lockdown are determined by local policymakers such as mayors, considering the cognition of the coronavirus behaviour and the spread rate. The various types of strategies have been set during lockdown periods such as closuring industries, recreational centers, restaurants, and various jobs; prohibiting traffic at certain times, prohibiting entry and exit from/into high-risk cities/regions; controlling the number of people present indoors; avoiding parties, ceremonies, festivals, or some effective gatherings; requiring the use of PPE and disinfectants. Although the waste composition had been demonstrated to be independent of its generation rate (Edjabou et al., 2015), further research is still needed to inspect this rule during the pandemic era. The recent studies (reviewed in Table 1) have shown that new compositions have been observed in different types of waste generated during the COVID-19 era; The results of statistical analysis of waste composition and changes caused by COVID-19 in Turkey performed by Özşeker et al. (2022) as well as the survey conducted by Kasim et al. (2021) in Guyana and Nigeria are confirmatory. Hence, it is anticipated that changes in waste generation rate in COVID-19 would be accompanied by changes in waste composition.

The increasing trend of MW generation corresponds to the outbreak curve of COVID-19 (Klemeš et al., 2020; Purnomo et al., 2021). There is a low probability that the reduction of elective medical services (Naughton, 2020) will offset the increase of MW generation from medical services to patients with COVID-19 in hospitals during the outbreak. The decrease in the tonnage of industrial/commercial waste and the increase in residential waste are also different for developed and developing countries during and after the COVID-19 era (Yousefi et al., 2021). A fixed solution cannot be suggested for waste management systems in different countries. Fig. 4 represents the idea that how trend curve of MSW generation can be different in developed and developing countries.

Reports have indicated shreds of evidence of a reduction in MSW generation in developed and more industrialized societies, such as North

Table 1
Challenges associated with waste generation and composition in the COVID-19 era.

Waste type	Waste origin/composition	Status	Affecting factors
MSW	Residential and household	Increased generation	Lockdown, staying at home, (Filho et al., 2021; Qian et al., 2020; Sarkodie and Owusu, 2021) Remote working (Scharadin et al., 2021) Changing routine cleaning and cooking habits (Richter et al., 2021b; Vidal-Mones et al., 2021)
		Infectious waste is added to the composition	Performing hygiene and isolation protocols at home (Haque et al., 2021a; Ouhsine et al., 2020)
	Industrial	Decreased generation	Lockdown, economic crises (Fan et al., 2021; Sharma et al., 2020; Tripathi et al., 2020)
	Municipal services	Decreased generation	Closuring recreational areas (Liang et al., 2021; Loizia et al., 2021; Yousefi et al., 2021) Infectious waste generation in urban public spaces (Amoruso and Baldovin, 2021; Ardiana et al., 2020; Ryan et al., 2020)
	Commercial & institutional	Decreased generation	Lockdown, remote working (Filimonau, 2020; Sharma et al., 2020; Tripathi et al., 2020)
	Construction & demolition	Decreased generation	Prolonged lockdown (Cai et al., 2021)
	Plastic	Increased generation	Online shopping and product packaging (Parashar and Hait, 2021; Vanapalli et al., 2021) Supplying disinfectants (Purnomo et al., 2021; Tripathi et al., 2020) Using personal protective equipment (PPE) (Hicks et al., 2021; Rowan and Laffey, 2021; Torres and De-la-Torre, 2021) Increased demand for popular immunity booster medicines and pharmaceutical packaging (Vanapalli et al., 2021) Increased tendency to use takeout and single-use plastic containers (Tripathi et al., 2020; Vanapalli et al., 2021) Suspending prohibitions and costs of plastic bags usage (Naughton, 2020)
	Food & green[a]	Relative probability of decreased generation	Closuring restaurants (Sharma et al., 2020) Attempting to cook at home, proper planning of meals, preserving and using leftover food (Babbitt et al., 2021) Preparing and buying food more carefully (Jribi et al., 2020; Principato et al., 2020) Losing jobs for the household heads (Scharadin et al., 2021)
		Relative probability of increased generation	Struggling restaurants to survive under restrictions of the COVID-19 era with the supply of takeout food (Ikiz et al., 2021) Lockdown conditions and breaking the food supply chain (Aldaco et al., 2020; Vidal-Mones et al., 2021) Buying too much food and not consuming a good proportion of stockpiled food (Babbitt et al., 2021; Brizi and Biraglia, 2021)
	Paper	Decreased generation	Closuring education sector Decreased demand for printing, writing, and advertising (Staub, 2020a)
		Relative probability of increased generation	High demand for wipes & toilet paper that incorporates less recycled fiber (Karidis, 2020)
	Cardboard	Increased generation	Online shopping and product packaging (Ikiz et al., 2021; Sharma et al., 2020; Yousefi et al., 2021)
	Other compositions	No available information	–
AW	Supply chain	Relative probability of increased generation	Lockdown, closuring food process industries and breaking the chain (Aldaco et al., 2020; Frankowski et al., 2020)
MW	All origins and total compositions, especially infectious	Increased generation	Diagnostic and confirmatory tests, One thousand PCR tests for COVID-19 generate 37 kg of plastic waste (Celis et al., 2021) Admission and hospitalization of COVID-19 patients 27% increase in weight of clinical waste generation (Agamuthu and Barasarathi, 2021) 3.4 kg/person.day increase in health-care facilities waste associated with COVID-19 (Purnomo et al., 2021; Tsukiji et al., 2020) 3.2, 1.8 and 0.1 kg/patient daily production rates of infectious MW by confirmed, suspected and out-patients, respectively (Wang et al., 2021) Added hospital beds (Patrício Silva et al., 2021) Construction of temporary health facilities (Sharma et al., 2020) High demand for glass vials in producing and distributing COVID-19 vaccines (Bothwell, 2021)

[a] Various societies have significantly different behaviours related to food waste (Ouhsine et al., 2020; Qian et al., 2020). The status of food and green waste generation is not exactly predictable.

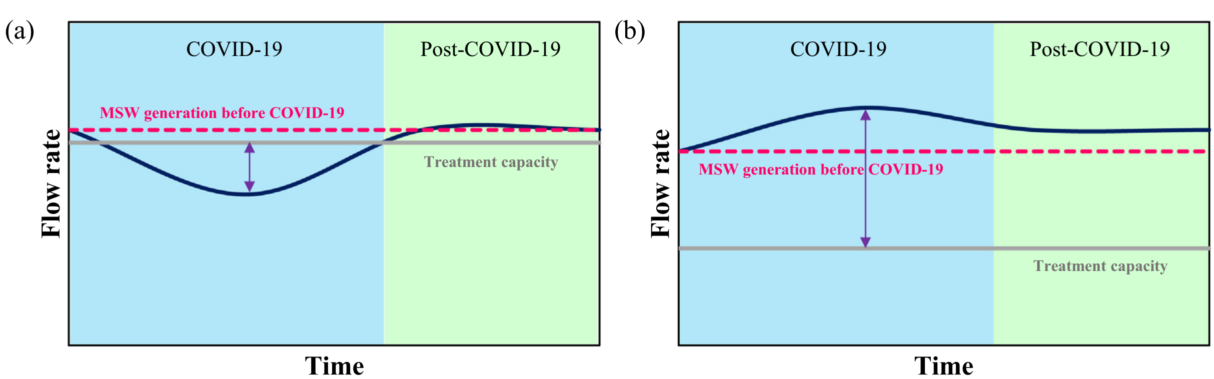

Fig. 4. Trend curve of MSW generation flow rate in (a) developed (more industrial) and (b) developing (less industrial) societies (city or country) during and after the COVID-19 era.

American countries and China, which have reportedly experienced a 5–30% waste generation reduction (Sharma et al., 2020; Staub, 2020b). It is predicted that they will be able to control the tonnage of MSW generation at the pre-outbreak rate through proper training. The less industrialized societies experienced a 3–20% increase in MSW generation during the COVID-19 era (Cai et al., 2021; Fan et al., 2021). The reasons can be mentioned as the higher share of residential and household waste compared to commercial and industrial waste and waste mismanagement (Kasim et al., 2021; Oyedotun et al., 2020). Some developing countries, such as Iran, started implementing source separation programs before COVID-19, but they failed (IMO, 2020; Zand and Heir, 2021b). Such failure has been attributed to difficulties in controlling pandemics, which later affected waste management programs by facing them with increased waste generation (Chen et al., 2021; Zand and Heir, 2021b). It cannot be expected that they are strong to damp the COVID-19 impulse on post-COVID-19. Further research is still needed to study the necessary interventions to return the waste management status in developing countries back into their stable conditions before the COVID-19 outbreak within a medium or long-term perspective (Ikiz et al., 2021).

2.2. Management technique

2.2.1. Waste management hierarchy: policies and legislations

The waste management hierarchy prioritises preferred programs based on sustainability by an integrated approach. The European Commission introduced the waste management hierarchy in the Waste Framework Directive (75/442/EEC), which has since been applied as a priority order to formulate waste management system policies and regulations (Hansen et al., 2002). The most common hierarchy is 4Rs, arranged in several levels of a pyramid chart and includes reduction, reuse, recycling, and recovery of energy (EUR-Lex, 2018). As depicted in Fig. 5, the prevalence of the COVID-19 pandemic has threatened this hierarchy prioritization.

Waste reduction has stood at the top of the waste management hierarchy as the most efficient and sustainable approach to protect the ecosphere against waste issues. Many countries had targeted waste reduction, but the occurrence of COVID-19 has halted achieving such a valuable goal (Ikiz et al., 2021). COVID-19 can be taken as a golden opportunity, at least in terms of waste reduction, due to the big changes it could create in the structure of traditional social activities. As an example, online meetings/conferences are now widely used as alternatives to in-person counterparts. However, low participation hindered achieving such an important goal at the beginning of the new trend.

Waste recycling and reuse follow the waste reduction strategy in the waste management hierarchy. The COVID-19 pandemic has also caused big changes in recycling and reuse strategies. The collection services of old furniture, clothes, and electronic wastes are good examples in this context showing suspended plans caused by the pandemic (Ikiz et al., 2021). The use of reusable containers has been prohibited in restaurants and cafes during the COVID-19 outbreak; disposable containers are encouraged instead to avoid virus transmission (Tripathi et al., 2020). The health protocols have also stressed employing single-use plastic bags in shopping malls and stores (Naughton, 2020). This is because fomites have been regarded as important disease transmitters, especially at the beginning of the COVID-19 outbreak. Chin et al. (2020) and Harbourt et al. (2020) measured coronavirus survival time on various surfaces. The researchers tested various temperature and humidity conditions. Most survival time was determined for non-porous and impermeable surfaces (more than 7 d at 65% relative humidity and 22 °C temperature) such as steel, plastic, and surgical masks (Aboubakr et al., 2020; Choi et al., 2021). The over-increasing concern about virus survival on the surfaces of different objects and the subsequent fear of probable transmission have changed the position of reduction, reuse, and recycling in the waste management hierarchy pyramid. The protocol codification, such as suspending reuse and recycling processes, has undermined the economy of the waste-to-material industry (Zhou et al., 2021). Scientific understanding of the virus has changed by gathered evidence since the COVID-19 outbreak. Studies have shown that coronavirus is transmitted primarily through respiratory droplets and person-to-person contacts (Choi et al., 2021; Lewis, 2021; WHO, 2020). Although it is definitely difficult to deny virus transmission through surface-to-person (Lewis, 2021), the transmission efficiency of this route is so low that the risk can be reduced by precautions such as disinfecting hands (Choi et al., 2021). It is possible to revitalise the activities of sorting, segregation, and recycling in the COVID-19 era by daily hygiene tests of employees, including temperature checks, forcing the use of PPE, installing plexiglass separators between sorting stations, hand washing stations, and portable toilets (Tripathi et al., 2020; Yousefi et al., 2021). These actions just can temporarily revive the waste-to-material industry. At the same time, the circular economy approach needs to be followed to maintain recycling, reuse, and reduction in the post-Covoid-19 era and even during other pandemics (Carenbauer, 2021; Neumeyer et al., 2020; Pikoń et al., 2021; Rada et al., 2020) and becomes a “business as usual”. Sharma et al. (2021) suggested using the COVID-19 response fund to facilitate the transition to full acceptance of the circular economy approach. However, it cannot be said with certainty that the circular economy will benefit from the COVID-19 impulse because it faces obstacles. These obstacles fall into three categories: (1) public participation, (2) technology, and (3) policy. The policy has a more pronounced effect by regulating and controlling the behaviour of production, technology, and consumption (Neves and Marques, 2022). Overcoming obstacles requires recognizing the mutual linkages and actions at different levels of the waste management system (Salmenperä et al., 2021). This issue is a research need today.

2.2.2. From collection to treatment

According to the information shown in Table 1, the COVID-19 impulse has consequences such as changes in the amount and source of waste generation (i.e., from commercial and industrial centers to residential areas), encountering new compositions (e.g., infectious waste in residential

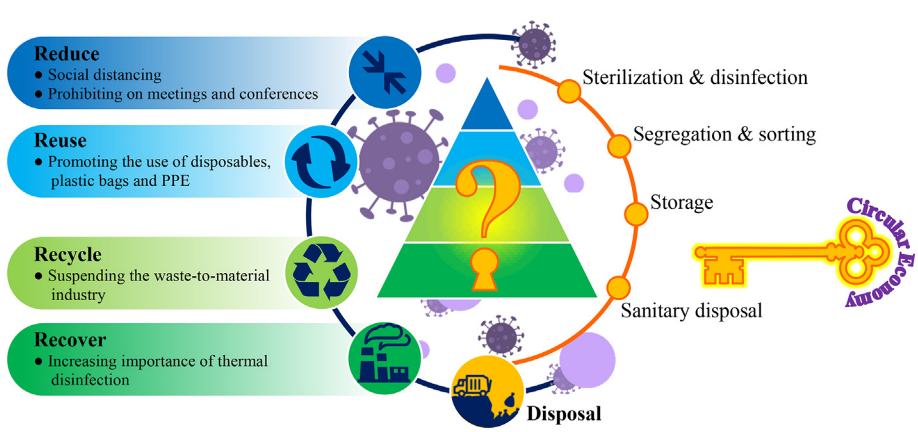

Fig. 5. Waste management hierarchy on the COVID-19 era.

origin), and variation in waste fractions (e.g., recyclable materials). As discussed earlier, the trend of changes in waste generation and its composition and all the subsequent observations during and post-COVID-19 have regional origins and vary from region to region. Accordingly, in countries struggling with severe epidemic challenges, waste management practices (including all stages from collection to treatment) are affected; But the effect intensity would be different (Fan et al., 2021). One of the challenges that waste policymakers face, especially in less developed and emerging countries is the capacity constraint (Kaza et al., 2018; Nzediegwu and Chang, 2020; Tsukiji et al., 2020). The other challenges are also summarised in Table 2.

It has been reportedly shown that less than half of the generated waste (i.e., on average 48%) in low-income countries is collected by waste collection systems in their urban areas, which is much lower than that in high-income countries (Kaza et al., 2018). Collection services, if managed properly, can, to a great extent, reduce the negative impacts on public health and the ecosystem by safely transferring waste streams from sources to processing and treatment facilities (Eren and Rıfat Tuzkaya, 2021; Liu et al., 2021; Yu et al., 2020). The deep changes observed in the waste generation driven by the COVID-19 outbreak necessitate reviewing waste transportation systems regarding service schedules, frequency of waste collection, and safety training for contractors and operators. Contractors who are responsible for waste collection in municipalities play a key role during and post-COVID-19 era. This prompted some researchers to focus on optimizing contractors' operational decisions using linear programming models (Tirkolaee et al., 2021; Tirkolaee and Aydın, 2021) and metaheuristic algorithms (Liu et al., 2020). The results can help contractors to a better plan. Valizadeh and Mozafari (2021) presented a mathematical model that helps motivate contractors to form large coalitions in the COVID-19 pandemic. In another study, Valizadeh et al. (2021) also considered policymakers in adopting complex and supportive policies.

Several models of MSW collection services are in use in different countries; among them, the door-to-door collection is the most prevalent one (Kaza et al., 2018). It is recommended to minimize close contact when collecting waste during the COVID-19 era. This issue has led to the stop of the collection of recyclable or reusable materials (Tripathi et al., 2020) while reducing the selective collection (Ragazzi et al., 2020). Some collection services, specialized for special waste, have also been suspended in some countries during the pandemic outbreak. The special waste, recyclable and reusable materials have been mixed with other waste streams, keeping us away from the targets set by the waste management hierarchy (Ikiz et al., 2021). The method of waste disposal highly depends on the available infrastructure and technologies and the economic situation. The high-income and developed countries have developed various waste disposal and treatment technologies, and they select the proper method based on their social, environmental, and economic targets. On the contrary, waste disposal in developing and low-income countries mostly rely on open-dumping (i.e., on average 76.7%) (Kaza et al., 2018). It can be concluded that a significant fraction of recyclable MSW appears in the mixed MSW stream by changing the origin of generation, which can be returned to the recycling stream if the sorting load increases; otherwise, would be buried with mixed MSW. Although the latter is more likely, a disinfection stage is required in both cases. The financial and environmental consequences on adding disinfection are still a research gap in the COVID era.

In the pandemic era, sterilization/disinfection is an essential step in all waste management systems (Vanapalli et al., 2021) which can be performed through thermal (e.g., incineration, carbonization, gasification, pyrolysis), physical (e.g., microwave, autoclave), or chemical treatments (e.g., chlorine-based, non-chlorine based) (Ilyas et al., 2020; Wang et al., 2020). In an ideal waste management model, the infectious wastes generated in the hospital and medical centers are segregated/sorted, sterilized, and then transferred to the temporary storage places within the hospitals. The capacity of temporary storage places is designed to fit the hospitals'

Table 2
Challenges related to stages of a management system from collection to final disposal of waste during the COVID-19 era.

Stages	Type of challenges						Description
	Ec	En	H	O	S	T	
Origin-segregation				*	*		Needs to retrain citizens and manufacturers to segregate infectious waste in labelled or coloured sealed bags (Tsukiji et al., 2020)
Collection & transportation			*	*	*		Suspension of special, reusable, and recyclable waste collection systems (Ikiz et al., 2021)
			*		*		Informal section collectors (Moonsammy et al., 2021; Tsukiji et al., 2020)
		*	*	*			Needs to change service schedule and waste collection times (Sharma et al., 2020)
	*	*	*	*			Control of transport system including route, time, origin, and destination of movement (Yang et al., 2021)
	*	*		*			Allocation of human resources and vehicles (Kulkarni and Anantharama, 2020)
Sorting				*			Low capacity of mechanical waste segregation facilities
			*				Exposing employees to infection via manual waste sorting
	*			*			Increasing the sorting load caused by improper/lack of origin-segregation program (Sharma et al., 2020)
Storage			*	*			Limited capacity of temporary storage facilities
		*	*			*	Location and other environmental conditions (temperature, humidity, etc.) of the facility (Kulkarni and Anantharama, 2020; Yang et al., 2021)
			*	*			Identify the origin and characteristics of waste that is transferred to temporary storage facilities (Kulkarni and Anantharama, 2020)
Disinfection			*			*	Knowing virus behaviour and its survival conditions (Kulkarni and Anantharama, 2020)
	*		*	*			The limited capacity of hospital sterilization facilities
	*			*		*	Structure inflexibility of integrated management facilities to add a disinfection stage (Purnomo et al., 2021)
Processing (WtM)	*	*	*	*			Suspension of recycling (Ikiz et al., 2021; Tripathi et al., 2020) and composting processes (Zand and Heir, 2020)
	*				*		Reducing demand for recycled materials, revenue and international trade in secondary materials (Zhou et al., 2021)
			*	*	*		Staff shortages due to concerns about exposure to infection (Sharma et al., 2020)
	*		*	*		*	Requiring disinfection stage
	*			*			Transferring more recyclable waste to the landfill and reducing landfill life (Urban and Nakada, 2021)
		*			*	*	Half-eaten packaged food in sealed polymer bags and prolonged biochemical decomposition (Mohammad et al., 2021)
Processing (WtE)	*			*			The limited capacity of fixed facilities
	*						High investment and operating costs
			*			*	Severe ecological hazard without specialized flue gas filtration and fly ash purification, especially in mobile facilities (Yang et al., 2021)
	*					*	Needing more research and commercial development of advanced technologies (Purnomo et al., 2021)
	*					*	Lack of technical knowledge and other scientific and economic resources for waste management in the developing country (Sharma et al., 2020)
						*	Knowing the fate of the virus in the biochemical decomposition processes (Bardi and Oliaee, 2021)
			*			*	Polymeric materials and face masks in the organic fraction of MSW, used for biological/chemical treatment (Pereira de Albuquerque et al., 2021)
Dumping		*	*	*			Requiring disinfection stage
		*					Soil and groundwater pollution (Sharma et al., 2020)
		*			*		Increasing the practice of self-disposal in developing and less developed countries (Moonsammy et al., 2021)

Ec: Economical; En: Environmental; H: Health; O: Operational; S: Social; T: Technical.

requirements (Yang et al., 2021). The most common infectious waste sterilization equipment used in hospitals is autoclave, microwave, and incinerator (Tsukiji et al., 2020). The chlorine-based disinfectants are also used if the waste volume is small (Ganguly and Chakraborty, 2021). After a short storage time, the disinfected MW or ashes are transported to the landfills. At the peak of the COVID-19 outbreak, the biggest challenge was hospitals' limited sterilization capacity, which was insufficient compared to the total volume of daily generated infectious wastes (Yang et al., 2021). To deal with this limitation during such tragic pandemic, policymakers adopted some new policies such as co-processing of MSW and MW, the use of industrial furnaces, cement kilns, non-local and/or mobile treatment plants to compensate for the shortages in sterilization capacity (Tsukiji et al., 2020; Yang et al., 2021). Such a strategy could not be realistic and possible in low-income and less industrialized countries, so the only viable solution was the direct landfilling of infectious wastes. Sharma et al. (2020) presented a plan to build small pits for sanitary landfills, which was later modified by other researchers (Mohammad et al., 2021).

On the other hand, the increasing probability of marine and river pollution caused by the released plastic wastes has brought about double concerns wordlwide in the same period (Chowdhury et al., 2021; Dharmaraj et al., 2021; Patrício Silva et al., 2020). The use of disposable plastics and PPE (masks, gloves, goggles, gowns, and disinfectant bottles) has increased during the COVID-19 pandemic, while at the same time, waste recycling has decreased (Ardusso et al., 2021; Benson et al., 2021). Although few researches showed that some policies such as restricting population mobility and shutting down some social activities could reduce the generation of some types of wastes such as plastics in coastal settlements and seafront promenades during lockdown (Loizia et al., 2021; Tassakka et al., 2020), the widespread use of antiviral polymer textiles containing Ag and Cu nanoparticles increased the possibility of some long-term negative effects on marine ecosystem (Ardusso et al., 2021). To understand the magnitude of the problem, Roy et al. (2021) attempted to design and model configurations for trapping/stopping buoyant plastic and non-woven textile materials used in PPE and tested them in an artificial river. Tabatabaei et al. (2021) assessed the environmental consequences of the production and consumption of different types of PPE during the epidemic using life cycle assessment.

The expansion of waste management systems has long been at the top of the agenda of urban policymakers in developing countries because of the ever-increasing waste generation trends even before the COVID-19 era. The challenges of the COVID-19 and other possible unknown pandemics in the future have also increased the importance of improvements in waste management systems especially choosing the best disposal and treatment method. In this era, some researchers have evaluated different disinfection, treatment, and disposal technologies by combining fuzzy theory and multi-criteria decision-making methods by combining different criteria (Ali Shah et al., 2021; Belhadi et al., 2020; Manupati et al., 2021). Purnomo et al. (2021) and Ganguly and Chakraborty (2021) studied the pros and cons of different technologies such as Torrefaction, hydrothermal carbonization, pyrolysis, gasification, plasma gasification, incineration. They made some recommendations for choosing the best possible technology (ies). However, some emergency management decision-makers believe that “disaster is the wrong time to exchange business cards”, meaning that the epidemic peak is the wrong time to start installing new waste management systems (Tsukiji et al., 2020). An in-depth engineering analysis can ensure that the proposed options can be able to counter the dynamic and changeable nature of the coronavirus or any other future pandemic.

2.3. Impacts on 3E fields (economy, energy, environment)

Implementation of full or partial lockdown has led to an economic recession at around 20–40% by reducing commercial and industrial operations (IEA, 2021, 2020b). Oil demand, more than 60% of which is used in the transportation and aviation sectors, has declined, and electricity demand has significantly shrunk like a prolonged Sunday (IEA, 2020a).

The declined fuel demand in the transportation sector has affected the use of renewable biofuels, so some ethanol and biodiesel plants in Brazil, European Union, and the United States have responded to such changes by reducing their production. The high demands for disinfectants during this period have motivated some biofuel production plants to target the production of disinfectants (Weber et al., 2020). Electricity generation from bio-feedstock has also declined due to interruptions in the solid biofuel supply chain for large power plants (IEA, 2020a). Bioenergy in the electricity sector has been affected less by the COVID-19 impulse, as its capacity has increased in 2019 and 2020 (IRENA, 2021). Zhou et al. (2021) examined the quarterly financial statements of 30 solid waste industry companies on the China Stock Market and reported a 21% increase in WtE industry turnover. They explained that MSW incinerators were used to treat non-hazardous MW (e.g., masks and gowns) to ensure the safe disposal of MW. These types of wastes have a high calorific value which explains why subsidies from electricity sales could increase during the COVID-19 pandemic. In addition, the gate fee has shrunk for MSW disposal at WtE facilities by reducing MSW generation in China.

The solid waste industry has another dimension: the market of recycling and WtM, which has not escaped the impulse of COVID-19. This is the second impulse to WtM after China's solid waste import ban in January 2018 (Ren et al., 2020; Ryter et al., 2021). The consequences of lockdown, the enforced health protocols, and decreased demand for raw materials have caused the recession in its market. Zhou et al. (2021) concluded that part of the recession would be attributed to lower secondary material prices. It is a weak probability that the Chinese government will be encouraged to reopen imports high-quality recycled materials (Huang et al., 2020). If the negative impact of the COVID-19 continues, the scale and capacity of the WtM industry will shrink (Zhou et al., 2021). Despite the massive diversion of waste flows from WtM to WtE can potentially reduce the threat of COVID-19 and any other pandemics to the waste management system, it may raise new environmental concerns that can undermine sustainable development (Manupati et al., 2021). Certainly, governments can reduce such challenges by paying more attention to research and development centers, providing more funding sources, and establishing appropriate policies (IEA, 2020b). Yao (2021) developed a fuzzy AHP model to determine the magnitude of impacts imposed by socio-economic development policies as the most critical criterion for starting green economic development and achieving sustainable development in the post-COVID-19 scenario.

Other challenges will also appear if a waste management system is considered at the micro-level. Tripathi et al. (2020) suggested using paper bags to collect recyclable wastes because the survival time of coronavirus on the surface of the paper is much shorter than that on plastic bags. Klemeš et al. (2020) prioritised the use of plastic bags in this context as they showed that the energy and water footprints of plastic bags per bag weight are lower than those of paper bags. The reduction of oil prices at the beginning of the COVID-19 outbreak could decrease the production cost of virgin plastics, causing that plastics recycling not to be cost-effective during that period. As a high fraction of MW and PPE are plastic wastes, thermal treatment is recommended to stop spreading viral infection (Tripathi et al., 2020). Although incinerators produce a lot of carbon emissions and require flue gas treatment technologies and CO_2 capture and storage, there are also advanced technologies, some of which have not yet reached maturity and commercialization (Purnomo et al., 2021). Zhao and You (2021) simulated the respirator processing of pyrolysis and incinerators and compared them using techno-economic and life cycle assessment approaches. They found that pyrolysis has 60% less emissions than incinerators. The recovery of energy from thermal treatment of infectious wastes can further decrease their environmental impacts and economic performance (Hong et al., 2018).

3. Necessities and recommendations for adapting waste management system

The COVID-19 outbreak has created several unpredicted challenges for waste management systems that this paper tried to compile a comprehensive summary of them. Some countries have experienced several waves of COVID-19 and passed several COVID-19 pandemic peaks at different time intervals. The lessons learned from each pandemic peak were used by policymakers to deal with the potential challenges of the forthcoming waves. Moreover, as time passed, some new but limited knowledge of coronavirus behaviour (e.g., their survival time on the surface of objects) has been explored. In addition to all the challenges, the COVID-19 pandemic has become an opportunity to improve and increase flexibility in the affected systems, interpreted as adaptability. In this opportunity, strategies that maintain the system on the path of sustainable development should be presented as necessary to adapt the management approach to the epidemic conditions in the waste system. Supporting the circular economy is one strategy that is not possible without recycling. Waste recycling at pandemic conditions can be performed in the form of mid-and long-term plans at three steps (Harrison and Thomas, 2020): (I) Supporting local recycling programs by policies and regulations (tax reduction, financial security, creativity, and innovation in the collection, sorting, recyclability of materials and the resilience of the system in adding new materials to it, as well as new recycling technologies); (II) significant and targeted investment in domestic infrastructure and final markets; and (III) extensive stakeholder participation.

In addition to the use of PPE and observance of social distance, it seems appropriate to suggest the following items: providing new training on segregation strategies to help reduce waste generation (Tsukiji et al., 2020); keeping recyclable waste in plastic bags for a longer time (more than 72 h, depending on how long the virus survives on different surfaces) by generators and citizens (Tripathi et al., 2020); Investing on safety equipment and physical infrastructure of collection, disinfection and mechanical sorting to reduce the burden of manual systems that help revived WtM and recycling (Sharma et al., 2020).

In the post-COVID-19 era, the extension of information and communication technology can protect waste management systems from the challenges of other pandemics and will provide a platform for expanding the use of online applications with artificial intelligence, especially in waste collection and segregation (Mohammad et al., 2021; Sharma et al., 2020). The expansion of temporary storage facilities can be beneficial even in a natural disaster. Temporary storage facilities can be equipped with pre-treatment, waste volume reduction, and screening technologies. While waste is awaiting final disposal, its processing management becomes easier by monitoring changes in composition and generation rate of waste (Kulkarni and Anantharama, 2020). For example, the composting process is suspended during the early COVID-19 pandemic (Zand and Heir, 2021a, 2021b). The storage of food waste in storage facilities located in safe places away from the cities can help revitalized composting process during the suspension. The presence of partially eaten packaged food in sealed bags and prolonged biochemical decomposition is another challenge in this process (Mohammad et al., 2021). Another viewpoint proposes a decentralized waste management approach (waste treatment in the vicinity of its generation source), similar to infectious MW in hospitals (Kulkarni and Anantharama, 2020). The use of portable incinerators is included in this program. Although it has a lower priority than fixed facilities due to the need for ancillary facilities (thermal energy utilization system and flue gas purification system), social partnerships can be used to invest in them (Yang et al., 2021).

A major concern for the post-COVID-19 is the incentives decline in implementing the circular economy that could challenge recycling as one of the steps to sustainable development. One solution is the guidance of laws and policies from now. Although there is a limitation of information for highlighting some challenges over others, this can lead to reasonable initial judgments. Gathering more accurate information can pave the way for adapting to each pandemic's dynamic and changeable nature through dynamic modeling and situation analysis, such as mapping of waste generation sources, which can provide the background for identifying waste flow changes to innovate and increase efficiency in the waste management system. Fig. 6 summarises all the proposed solutions to create and increase adaptability in the waste management system to the COVID-19 era and beyond.

4. Conclusions

COVID-19 has been an impulse on various systems, including waste management. The intensity of the imposed impulse depends on the epidemic duration and the adaptation of systems to it. Therefore, adapting to the pandemic era has become a necessity in systems, and detailed knowledge of the challenges that appeared in this era can help choose the appropriate adaptation strategies. This study reviews various sources to answer the challenges of the waste management system from generation to final disposal of waste; Such a complete set has not been provided so far. In addition, it

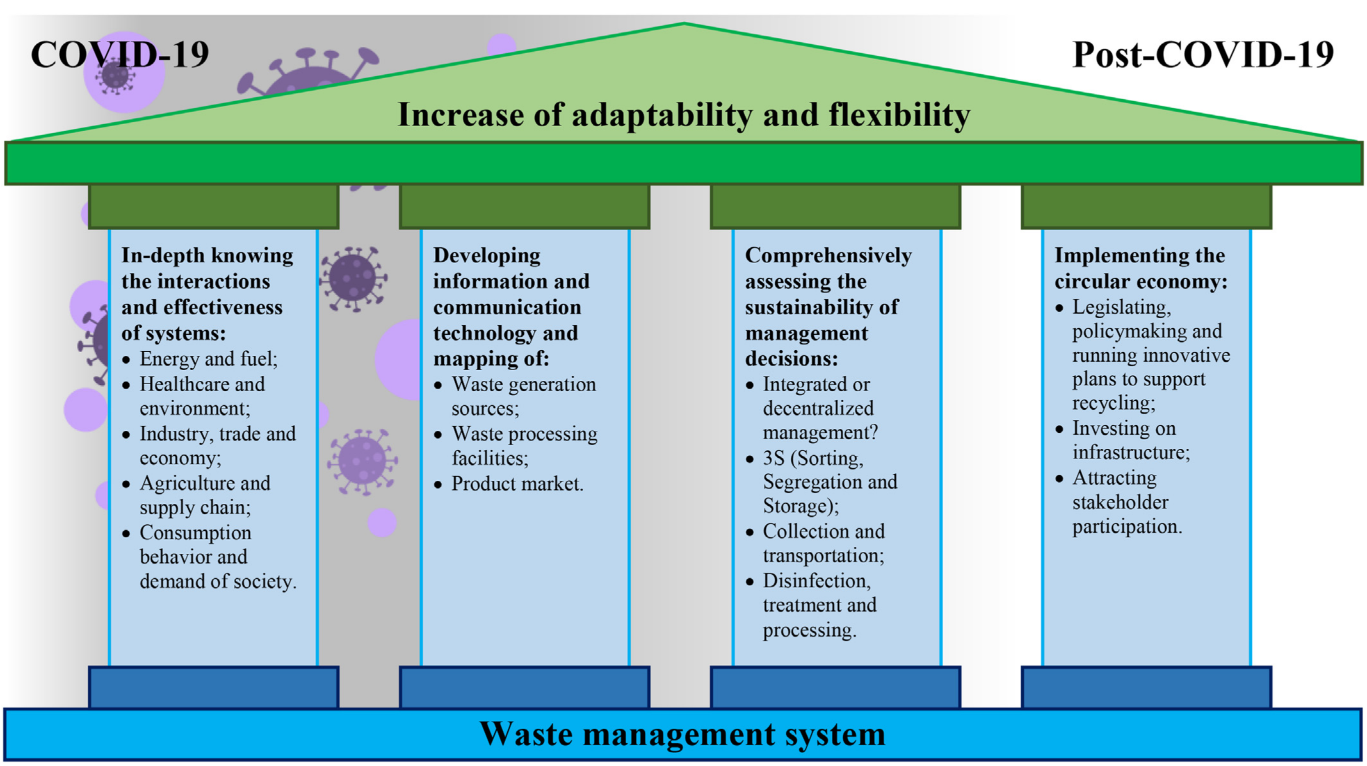

Fig. 6. The set of solutions to increase the adaptability and flexibility of the waste management system in the COVID-19 and post-COVID-19 era.

considers the micro and macro levels of the waste management system and enumerates the four basic pillars for flexibility and adaptability of the waste management system. There will be many research opportunities to analyse waste generation and composition and evaluate the interventions needed to control their dynamic nature as data limitations are broken. This can be useful for gaining an in-depth knowledge of the interactions of the waste management system with other systems and mapping the various dimensions of waste generation sources and its processing product market and will be a step towards developing information and communication technology. Due to the diversity and differences in waste generation and composition in different geographical and economic regions, it is impossible to prescribe the same management decisions for all types of wastes. Therefore, assessing the sustainability of any decision for the implementation region can help the waste management system adapt to the region's environmental conditions. The prevalence of COVID-19 pandemics and the possibility of other unknown pandemics in the future are also recognized as a serious threat to prioritization in the waste management hierarchy, which degrades the status of reduction, reuse, and recycling. The short- and long-term confronting strategies proposed in various sources are reviewed in this study. Striving to support and implement the circular economy is one of the basic strategies that can create relative stability in the industry and market of WtM, and identifying its drivers and obstacles remains a research gap.

CRediT authorship contribution statement

Khadijeh Faraji Mahyari: Investigation, Writing – original draft. **Qiaoyu Sun:** Writing – original draft. **Jiří Jaromír Klemes:** Writing – review & editing, Supervision. **Mortaza Aghbashlo:** Writing – review & editing. **Meisam Tabatabaei:** Writing – review & editing. **Benyamin Khoshnevisan:** Writing – original draft, Writing – review & editing. **Morten Birkved:** Writing – original draft.

Declaration of competing interest

None.

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References

Abdoli, M.Al., 1993. Municipal solid waste management system and its control methods. Organization of Recycling and Conversion of Material of Tehran Municipality, 1st ed Organization of Recycling and Conversion of Material of Tehran Municipality, Tehran, I.R. Iran.

Aboubakr, H.A., Sharafeldin, T.A., Goyal, S.M., 2020. Stability of SARS-CoV-2 and other coronaviruses in the environment and on common touch surfaces and the influence of climatic conditions: a review. Transbound. Emerg. Dis. 00, 1–17. https://doi.org/10.1111/tbed.13707.

Agamuthu, P., Barasarathi, J., 2021. Clinical waste management under COVID-19 scenario in Malaysia. Waste Manag. Res. 39, 18–26. https://doi.org/10.1177/0734242X20959701.

Aghbashlo, M., Tabatabaei, M., Soltanian, S., Ghanavati, H., 2019a. Biopower and biofertilizer production from organic municipal solid waste: an exergoenvironmental analysis. Renew. Energy 143, 64–76.

Aghbashlo, M., Tabatabaei, M., Soltanian, S., Ghanavati, H., Dadak, A., 2019b. Comprehensive exergoeconomic analysis of a municipal solid waste digestion plant equipped with a biogas genset. Waste Manag. 87, 485–498.

Aktar, M.A., Alam, M.M., Al-Amin, A.Q., 2021. Global economic crisis, energy use, CO2 emissions, and policy roadmap amid COVID-19. Sustain. Prod. Consum. 26, 770–781. https://doi.org/10.1016/j.spc.2020.12.029.

Aldaco, R., Hoehn, D., Laso, J., Margallo, M., Ruiz-Salmón, J., Cristobal, J., Kahhat, R., Villanueva-Rey, P., Bala, A., Batlle-Bayer, L., Fullana-i-Palmer, P., Irabien, A., Vazquez-Rowe, I., 2020. Food waste management during the COVID-19 outbreak: a holistic climate, economic and nutritional approach. Sci. Total Environ. 742, 140524. https://doi.org/10.1016/j.scitotenv.2020.140524.

Ali Shah, S.A., Longsheng, C., Solangi, Y.A., Ahmad, M., Ali, S., 2021. Energy trilemma based prioritization of waste-to-energy technologies: implications for post-COVID-19 green economic recovery in Pakistan. J. Clean. Prod. 284, 124729. https://doi.org/10.1016/j.jclepro.2020.124729.

Amoruso, I., Baldovin, T., 2021. On-board toilets of long-haul flights: is sewage epidemiology effective for COVID-19 global surveillance? Travel Med. Infect. Dis. 40, 102006. https://doi.org/10.1016/j.tmaid.2021.102006.

Ardiana, N., Suryawan, I.W.K., Ridhosari, B., 2020. Challenges for hazardous waste management related to covid-19 pandemic at train station. Int. J. Adv. Trends Comput. Sci. Eng. 9, 8364–8370. https://doi.org/10.30534/ijatcse/2020/210952020.

Ardusso, M., Forero-López, A.D., Buzzi, N.S., Spetter, C.V., Fernández-Severini, M.D., 2021. COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America. Sci. Total Environ. 763, 144365. https://doi.org/10.1016/j.scitotenv.2020.144365.

Babbitt, C.W., Babbitt, G.A., Oehman, J.M., 2021. Behavioral impacts on residential food provisioning, use, and waste during the COVID-19 pandemic. Sustain. Prod. Consum. 28, 315–325. https://doi.org/10.1016/j.spc.2021.04.012.

Bardi, M.J., Oliaee, M.A., 2021. Impacts of different operational temperatures and organic loads in anaerobic co-digestion of food waste and sewage sludge on the fate of SARS-CoV-2. Process Saf. Environ. Prot. 146, 464–472. https://doi.org/10.1016/j.psep.2020.11.035.

Belhadi, A., Kamble, S.S., Khan, S.A.R., Touriki, F.E., Kumar, M., D., 2020. Infectious waste management strategy during COVID-19 pandemic in Africa: an integrated decision-making framework for selecting sustainable technologies. Environ. Manage. 66, 1085–1104. https://doi.org/10.1007/s00267-020-01375-5.

Benson, N.U., Fred-Ahmadu, O.H., Bassey, D.E., Atayero, A.A., 2021. COVID-19 pandemic and emerging plastic-based personal protective equipment waste pollution and management in Africa. J. Environ. Chem. Eng. 9, 105222. https://doi.org/10.1016/j.jece.2021.105222.

Bothwell, L., 2021. COVID-19's Impact on Glass Recycling [WWW Document]. Inf. Mark. https://www.waste360.com/recycling/covid-19s-impact-glass-recycling. (Accessed 15 June 2021).

Brizi, A., Biraglia, A., 2021. "Do I have enough food?" How need for cognitive closure and gender impact stockpiling and food waste during the COVID-19 pandemic: a cross-national study in India and the United States of America. Personal. Individ. Differ. 168, 110396. https://doi.org/10.1016/j.paid.2020.110396.

Brown, C., Milke, M., Seville, E., 2011. Disaster waste management: a review article. Waste Manag. 31, 1085–1098. https://doi.org/10.1016/j.wasman.2011.01.027.

Brunner, P.H., Rechberger, H., 2015. Waste to energy - key element for sustainable waste management. Waste Manag. 37, 3–12. https://doi.org/10.1016/j.wasman.2014.02.003.

Cai, M., Guy, C., Héroux, M., Lichtfouse, E., An, C., 2021. The impact of successive COVID-19 lockdowns on people mobility, lockdown efficiency, and municipal solid waste. Environ. Chem. Lett. 2021, 1–7. https://doi.org/10.1007/S10311-021-01290-Z.

Carenbauer, M.G., 2021. Essential or dismissible? Exploring the challenges of waste pickers in relation to COVID-19. Geoforum 120, 79–81. https://doi.org/10.1016/j.geoforum.2021.01.018.

Celis, J.E., Espejo, W., Paredes-Osses, E., Contreras, S.A., Chiang, G., Bahamonde, P., 2021. Plastic residues produced with confirmatory testing for COVID-19: classification, quantification, fate, and impacts on human health. Sci. Total Environ. 760, 144167. https://doi.org/10.1016/j.scitotenv.2020.144167.

Chen, F., Lou, J., Hu, J., Chen, H., Long, R., Li, W., 2021. Study on the relationship between crisis awareness and medical waste separation behavior shown by residents during the COVID-19 epidemic. Sci. Total Environ. 787, 147522. https://doi.org/10.1016/j.scitotenv.2021.147522.

Chin, A.W.H., Chu, J.T.S., Perera, M.R.A., Hui, K.P.Y., Yen, H.-L., Chan, M.C.W., Peiris, M., Poon, L.L.M., 2020. Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe 1, e10. https://doi.org/10.1016/s2666-5247(20)30003-3.

Choi, H., Chatterjee, P., Coppin, J.D., Martel, J.A., Hwang, M., Jinadatha, C., Sharma, V.K., 2021. Current understanding of the surface contamination and contact transmission of SARS-CoV-2 in healthcare settings. Environ. Chem. Lett. 1, 3. https://doi.org/10.1007/s10311-021-01186-y.

Chowdhury, H., Chowdhury, T., Sait, S.M., 2021. Estimating marine plastic pollution from COVID-19 face masks in coastal regions. Mar. Pollut. Bull. 168, 112419. https://doi.org/10.1016/j.marpolbul.2021.112419.

Cosgrove, K., Vizcaino, M., Wharton, C., 2021. COVID-19-related changes in perceived household food waste in the United States: a cross-sectional descriptive study. Int. J. Environ. Res. Public Health 18, 1–11. https://doi.org/10.3390/ijerph18031104.

Das, A.K., Islam, M.N., Billah, M.M., Sarker, A., 2021. COVID-19 pandemic and healthcare solid waste management strategy – a mini-review. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2021.146220.

Dharmaraj, S., Ashokkumar, V., Hariharan, S., Manibharathi, A., Show, P.L., Chong, C.T., Ngamcharussrivichai, C., 2021. The COVID-19 pandemic face mask waste: a blooming threat to the marine environment. Chemosphere 272, 129601. https://doi.org/10.1016/j.chemosphere.2021.129601.

Edalatpour, M.A., Al-e-hashem, S.M.J.M., Karimi, B., Bahli, B., 2018. Investigation on a novel sustainable model for waste management in megacities: a case study in Tehran municipality. Sustain. Cities Soc. 36, 286–301. https://doi.org/10.1016/j.scs.2017.09.019.

Edjabou, M.E., Jensen, M.B., Götze, R., Pivnenko, K., Petersen, C., Scheutz, C., Astrup, T.F., 2015. Municipal solid waste composition: sampling methodology, statistical analyses, and case study evaluation. Waste Manag. 36, 12–23. https://doi.org/10.1016/j.wasman.2014.11.009.

Eren, E., Rıfat Tuzkaya, U., 2021. Safe distance-based vehicle routing problem: medical waste collection case study in COVID-19 pandemic. Comput. Ind. Eng. 157, 107328. https://doi.org/10.1016/j.cie.2021.107328.

EUR-Lex, 2018. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives [WWW Document]. Eur. Union. http://data.europa.eu/eli/dir/2008/98/2018-07-05. (Accessed 6 April 2021).

Fan, Y.Van, Jiang, P., Hemzal, M., Klemeš, J.J., 2021. An update of COVID-19 influence on waste management. Sci. Total Environ. 754, 142014. https://doi.org/10.1016/j.scitotenv.2020.142014.

FAO, 2021. Food Loss and Waste Database [WWW Document]. Food Agric. Organ, United Nations. http://www.fao.org/platform-food-loss-waste/flw-data/en/. (Accessed 13 June 2021).

Filho, W.L., Voronova, V., Kloga, M., Paço, A., Minhas, A., Salvia, A.L., Ferreira, C.D., Sivapalan, S., 2021. COVID-19 and waste production in households: a trend analysis. Sci. Total Environ. 777, 145997. https://doi.org/10.1016/j.scitotenv.2021.145997.

Filimonau, V., 2020. The prospects of waste management in the hospitality sector post COVID-19. Resour. Conserv. Recycl. 105272. https://doi.org/10.1016/j.resconrec.2020.105272.

Frankowski, J., Zaborowicz, M., Dach, J., Czekała, W., Przybył, J., 2020. Biological waste management in the case of a pandemic emergency and other natural disasters. Determination of bioenergy production from floricultural waste and modeling of methane production using deep neural modeling methods. Energies 13, 3014. https://doi.org/10.3390/en13113014.

Ganguly, R.K., Chakraborty, S.K., 2021. Integrated approach in municipal solid waste management in COVID-19 pandemic: perspectives of a developing country like India in a global scenario. Case Stud. Chem. Environ. Eng. 3, 100087. https://doi.org/10.1016/j.cscee.2021.100087.

Hansen, W., Christopher, M., Verbuecheln, M., 2002. EU Waste Policy and Challenges for Regional and Local Authorities. Ecologic, Berlin, Germany.

Haque, M.S., Sharif, S., Masnoon, A., Rashid, E., 2021a. SARS-CoV-2 pandemic-induced PPE and single-use plastic waste generation scenario. Waste Manag. Res. 39, 3–17. https://doi.org/10.1177/0734242X20980828.

Haque, M.S., Uddin, S., Sayem, S.M., Mohib, K.M., 2021b. Coronavirus disease 2019 (COVID-19) induced waste scenario: a short overview. J. Environ. Chem. Eng. 9, 104660. https://doi.org/10.1016/j.jece.2020.104660.

Harbourt, D.E., Haddow, A.D., Piper, A.E., Bloomfield, H., Kearney, B.J., Fetterer, D., Gibson, K., Minogue, T., 2020. Modeling the stability of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on skin, currency, and clothing host infection biomarkers view project SARS-CoV-2 stability studies view project. PLoS Negl. Trop. Dis. 14. https://doi.org/10.1371/journal.pntd.0008831.

Harrison, K., Thomas, D.de, 2020. Rebuilding Recycling to Go Circular [WWW Document]. GreenBiz Gr. Inc. https://www.greenbiz.com/article/rebuilding-recycling-go-circular. (Accessed 12 May 2021).

Hicks, A., Temizel-Sekeryan, S., Kontar, W., Ghamkhar, R., Rodríguez Morris, M., 2021. Personal respiratory protection and resiliency in a pandemic, the evolving disposable versus reusable debate and its effect on waste generation. Resour. Conserv. Recycl. 168, 105262. https://doi.org/10.1016/j.resconrec.2020.105262.

Hong, Jingmin, Zhan, S., Yu, Z., Hong, Jinglan, Qi, C., 2018. Life-cycle environmental and economic assessment of medical waste treatment. J. Clean. Prod. 174, 65–73. https://doi.org/10.1016/j.jclepro.2017.10.206.

Huang, Q., Chen, G., Wang, Y., Chen, S., Xu, L., Wang, R., 2020. Modelling the global impact of China's ban on plastic waste imports. Resour. Conserv. Recycl. 154, 104607. https://doi.org/10.1016/J.RESCONREC.2019.104607.

IEA, 2020a. Global Energy Review 2020: The Impacts of the Covid-19 Crisis on Global Energy Demand and CO2 Emissions [WWW Document]. Int. Energy Agency. https://www.iea.org/reports/global-energy-review-2020. (Accessed 12 May 2021).

IEA, 2020b. Clean Energy Innovation in the Covid-19 Crisis: Investing Today to Ensure a Sustainable Tomorrow [WWW Document]. Int. Energy Agency. https://www.iea.org/articles/clean-energy-innovation-in-the-covid-19-crisis. (Accessed 12 May 2021).

IEA, 2021. Global Energy Review: CO2 Emissions in 2020 (Understanding the Impacts of Covid-19 on Global CO2 Emissions) [WWW Document]. Int. Energy Agency. https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020. (Accessed 12 May 2021).

Ikiz, E., Maclaren, V.W., Alfred, E., Sivanesan, S., 2021. Impact of COVID-19 on household waste flows, diversion and reuse: the case of multi-residential buildings in TorontoCanada. Resour. Conserv. Recycl. 164, 105111. https://doi.org/10.1016/j.resconrec.2020.105111.

Ilyas, S., Srivastava, R.R., Kim, H., 2020. Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. Sci. Total Environ. 749, 141652. https://doi.org/10.1016/j.scitotenv.2020.141652.

IMO, 2020. Waste Management, Ministry of Interior. Iran's Municipalities and village administrators Organization, Tehran, I.R. Iran.

IRENA, 2021. Statistics Time Series: Renewable Energy Capacity and Electricity Generation for Selected Countries and Technologies [WWW Document]. Int. Renew. Energy Agency. https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Statistics-Time-Series. (Accessed 12 May 2021).

Jribi, S., Ben Ismail, H., Doggui, D., Debbabi, H., 2020. COVID-19 virus outbreak lockdown: what impacts on household food wastage? Environ. Dev. Sustain. 22, 3939–3955. https://doi.org/10.1007/s10668-020-00740-y.

Karidis, A., 2020. COVID-19 Drives Major Fluxes in Paper Supply Chain [WWW Document]. Inf. Mark. https://www.waste360.com/paper/covid-19-drives-major-fluxes-paper-supply-chain. (Accessed 15 June 2021).

Kasim, O.F., Oyedotun, T.D.T., Famewo, A., Oyedotun, T.D., Moonsammy, S., Ally, N., Renn-Moonsammy, D.M., 2021. Household waste generation, change in waste composition and the exposure to COVID-19 in Guyana and Nigeria. Sci. Afr. 14, e01060. https://doi.org/10.1016/J.SCIAF.2021.E01060.

Kaza, S., Yao, L.C., Bhada-Tata, P., Van Woerden, F., 2018. What a waste 2.0 : a global snapshot of solid waste management to 2050, World Bank. Urban Development Series Knowledge Papaers. World Bank, Washington, D.C., USA https://doi.org/10.1596/978-1-4648-1329-0.

Khoshnevisan, B., Tabatabaei, M., Tsapekos, P., Rafiee, S., Aghbashlo, M., Lindeneg, S., Angelidaki, I., 2020. Environmental life cycle assessment of different biorefinery platforms valorizing municipal solid waste to bioenergy, microbial protein, lactic and succinic acid. Renew. Sustain. Energ. Rev. 117, 109493.

Klemeš, J.J., Fan, Y.Van, Tan, R.R., Jiang, P., 2020. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renew. Sustain. Energ. Rev. 127, 109883. https://doi.org/10.1016/j.rser.2020.109883.

Kulkarni, B.N., Anantharama, V., 2020. Repercussions of COVID-19 pandemic on municipal solid waste management: challenges and opportunities. Sci. Total Environ. 743, 140693. https://doi.org/10.1016/j.scitotenv.2020.140693.

Lewis, D., 2021. COVID-19 rarely spreads through surfaces. So why are we still deep cleaning? Nature 590, 26–28. https://doi.org/10.1038/d41586-021-00251-4.

Liang, Y., Song, Q., Wu, N., Li, J., Zhong, Y., Zeng, W., 2021. Repercussions of COVID-19 pandemic on solid waste generation and management strategies. Front. Environ. Sci. Eng. 15, 1–18. https://doi.org/10.1007/s11783-021-1407-5.

Liu, Z., Li, Z., Chen, W., Zhao, Y., Yue, H., Wu, Z., 2020. Path optimization of medical waste transport routes in the emergent public health event of covid-19: a hybrid optimization algorithm based on the immune–ant colony algorithm. Int. J. Environ. Res. Public Health 17, 1–18. https://doi.org/10.3390/ijerph17165831.

Liu, Z., Liu, T., Liu, X., Wei, A., Wang, X., Yin, Y., Li, Y., 2021. Research on optimization of healthcare waste management system based on green governance principle in the covid-19 pandemic. Int. J. Environ. Res. Public Health 18, 5316. https://doi.org/10.3390/ijerph18105316.

Loizia, P., Voukkali, I., Chatziparaskeva, G., Navarro-Pedreño, J., Zorpas, A.A., 2021. Measuring the level of environmental performance on coastal environment before and during the covid-19 pandemic: a case study from Cyprus. Sustainability 13, 1–25. https://doi.org/10.3390/su13052485.

Manupati, V.K., Ramkumar, M., Baba, V., Agarwal, A., 2021. Selection of the best healthcare waste disposal techniques during and post COVID-19 pandemic era. J. Clean. Prod. 281, 125175. https://doi.org/10.1016/j.jclepro.2020.125175.

Mohammad, A., Goli, V.S.N.S., Singh, D.N., 2021. Discussion on 'Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic, by Sharma et al. (2020)'. Resour. Conserv. Recycl. 164, 105175. https://doi.org/10.1016/j.resconrec.2020.105175.

Moonsammy, S., Oyedotun, T.D.T., Renn-Moonsammy, D.-M., Oyedotun, T.D., Ally, N., Kasim, O.F., Famewo, A., 2021. COVID-19 effects on municipality waste collection services for households: statistical modelling of perspectives from Guyana and Nigeria. J. Mater. Cycles Waste Manag. 234 (23), 1678–1687. https://doi.org/10.1007/S10163-021-01225-4 2021.

Naughton, C.C., 2020. Will the COVID-19 pandemic change waste generation and composition?: the need for more real-time waste management data and systems thinking. Resour. Conserv. Recycl. 162, 105050. https://doi.org/10.1016/j.resconrec.2020.105050.

Neumeyer, X., Ashton, W.S., Dentchev, N., 2020. Addressing resource and waste management challenges imposed by COVID-19: an entrepreneurship perspective. Resour. Conserv. Recycl. 162, 105058. https://doi.org/10.1016/j.resconrec.2020.105058.

Neves, S.A., Marques, A.C., 2022. Drivers and barriers in the transition from a linear economy to a circular economy. J. Clean. Prod. 341, 130865. https://doi.org/10.1016/J.JCLEPRO.2022.130865.

Nguyen, T.D.T., Kawai, K., Nakakubo, T., 2021. Estimation of COVID-19 waste generation and composition in Vietnam for pandemic management. Waste Manag. Res. 39, 1356–1364. https://doi.org/10.1177/0734242X211052849.

Nzediegwu, C., Chang, S.X., 2020. Improper solid waste management increases potential for COVID-19 spread in developing countries. Resour. Conserv. Recycl. 161, 104947. https://doi.org/10.1016/J.RESCONREC.2020.104947.

Ouhsine, O., Ouigmane, A., Layati, E., Aba, B., Isaifan, R.J., Berkani, M., 2020. Impact of COVID-19 on the qualitative and quantitative aspect of household solid waste. Glob. J. Environ. Sci. Manag. 6, 41–52. https://doi.org/10.22034/GJESM.2019.06.SI.05.

Oyedotun, T.D.T., Kasim, O.F., Famewo, A., Oyedotun, T.D., Moonsammy, S., Ally, N., Renn-Moonsammy, D.M., 2020. Municipal waste management in the era of COVID-19: perceptions, practices, and potentials for research in developing countries. Res. Glob. 2, 100033. https://doi.org/10.1016/J.RESGLO.2020.100033.

Özşeker, K., Terzi, Y., Erüz, C., 2022. Solid waste composition and COVID-19-induced changes in an inland water ecosystem in Turkey. Environ. Sci. Pollut. Res. 1, 1–10. https://doi.org/10.1007/S11356-022-19750-6/TABLES/3.

Parashar, N., Hait, S., 2021. Plastics in the time of COVID-19 pandemic: protector or polluter? Sci. Total Environ. 759, 144274. https://doi.org/10.1016/j.scitotenv.2020.144274.

Patrício Silva, A.L., Prata, J.C., Walker, T.R., Campos, D., Duarte, A.C., Soares, A.M.V.M., Barcelò, D., Rocha-Santos, T., 2020. Rethinking and optimising plastic waste management under COVID-19 pandemic: policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. Sci. Total Environ. 742, 140565. https://doi.org/10.1016/j.scitotenv.2020.140565.

Patrício Silva, A.L., Prata, J.C., Walker, T.R., Duarte, A.C., Ouyang, W., Barcelò, D., Rocha-Santos, T., 2021. Increased plastic pollution due to COVID-19 pandemic: challenges and recommendations. Chem. Eng. J. 405, 126683. https://doi.org/10.1016/j.cej.2020.126683.

Pereira de Albuquerque, F., Dhadwal, M., Dastyar, W., Mirsoleimani Azizi, S.M., Karidio, I., Zaman, H., Dhar, B.R., 2021. Fate of disposable face masks in high-solids anaerobic digestion: experimental observations and review of potential environmental implications. Case Stud. Chem. Environ. Eng. 3, 100082. https://doi.org/10.1016/J.CSCEE.2021.100082.

Pikoń, K., Poranek, N., Czajkowski, A., Łaźniewska-Piekarczyk, B., 2021. Poland's proposal for a safe solution of waste treatment during the covid-19 pandemic and circular economy connection. Appl. Sci. 11, 3939. https://doi.org/10.3390/app11093939.

Principato, L., Secondi, L., Cicatiello, C., Mattia, G., 2020. Caring more about food: the unexpected positive effect of the Covid-19 lockdown on household food management and waste. Socio Econ. Plan. Sci., 100953 https://doi.org/10.1016/j.seps.2020.100953.

Purnomo, C.W., Kurniawan, W., Aziz, M., 2021. Technological review on thermochemical conversion of COVID-19-related medical wastes. Resour. Conserv. Recycl. 167, 105429. https://doi.org/10.1016/j.resconrec.2021.105429.

Qian, K., Javadi, F., Hiramatsu, M., 2020. Influence of the COVID-19 pandemic on household food waste behavior in Japan. Sustainability 12, 9942. https://doi.org/10.3390/su12239942.

Rada, E.C., Magaril, E.R., Schiavon, M., Karaeva, A., Chashchin, M., Torretta, V., 2020. MSW management in universities: sharing best practices. Sustainability 12, 5084. https://doi.org/10.3390/su12125084.

Ragazzi, M., Rada, E.C., Schiavon, M., 2020. Municipal solid waste management during the SARS-COV-2 outbreak and lockdown ease: lessons from Italy. Sci. Total Environ. 745, 141159. https://doi.org/10.1016/j.scitotenv.2020.141159.

Rajaeifar, M.A., Ghanavati, H., Dashti, B.B., Heijungs, R., Aghbashlo, M., Tabatabaei, M., 2017. Electricity generation and GHG emission reduction potentials through different municipal solid waste management technologies: a comparative review. Renew. Sustain. Energ. Rev. 79, 414–439.

Ren, Y., Shi, L., Bardow, A., Geyer, R., Suh, S., 2020. Life-cycle environmental implications of China's ban on post-consumer plastics import. Resour. Conserv. Recycl. 156, 104699. https://doi.org/10.1016/J.RESCONREC.2020.104699.

Richter, A., Ng, K.T.W., Vu, H.L., Kabir, G., 2021a. Waste disposal characteristics and data variability in a mid-sized Canadian city during COVID-19. Waste Manag. 122, 49–54. https://doi.org/10.1016/j.wasman.2021.01.004.

Richter, A., Ng, K.T.W., Vu, H.L., Kabir, G., 2021b. Identification of behaviour patterns in waste collection and disposal during the first wave of COVID-19 in Regina, SaskatchewanCanada. J. Environ. Manage. 290, 112663. https://doi.org/10.1016/j.jenvman.2021.112663.

Rowan, N.J., Laffey, J.G., 2021. Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (COVID-19) pandemic – implications for efficacy, reuse and sustainable waste management. Sci. Total Environ. 752, 142259. https://doi.org/10.1016/j.scitotenv.2020.142259.

Roy, D., Pagliara, S., Palermo, M., 2021. Experimental analysis of structures for trapping sars-cov-2-related floating waste in rivers. Water (Switzerland) 13, 771. https://doi.org/10.3390/w13060771.

Ryan, P.G., Maclean, K., Weideman, E.A., 2020. The impact of the COVID-19 lockdown on urban street litter in South Africa. Environ. Process. 7, 1303–1312. https://doi.org/10.1007/s40710-020-00472-1.

Ryter, J., Fu, X., Bhuwalka, K., Roth, R., Olivetti, E.A., 2021. Emission impacts of China's solid waste import ban and COVID-19 in the copper supply chain. Nat. Commun. 121 (12), 1–13. https://doi.org/10.1038/s41467-021-23874-7 2021.

Salmenperä, H., Pitkänen, K., Kautto, P., Saikku, L., 2021. Critical factors for enhancing the circular economy in waste management. J. Clean. Prod. 280, 124339. https://doi.org/10.1016/J.JCLEPRO.2020.124339.

Sarkodie, S.A., Owusu, P.A., 2021. Impact of COVID-19 pandemic on waste management. Environ. Dev. Sustain. 23, 7951–7960. https://doi.org/10.1007/s10668-020-00956-y.

Scharadin, B., Yu, Y., Jaenicke, E.C., 2021. Household time activities, food waste, and diet quality: the impact of non-marginal changes due to COVID-19. Rev. Econ. Househ. 19, 399–428. https://doi.org/10.1007/s11150-021-09555-w.

Schiffer, H.-W., Westhuizen, Z.Van der, Radu, C., Ibeanu, N., Onyekpe, D.K., Notarianni, E., Menzel, C., 2016. World Energy Resources 2016: Waste to Energy. World Energy Council. World Energy Council, London, United Kingdom.

Sharma, H.B., Vanapalli, K.R., Cheela, V.S., Ranjan, V.P., Jaglan, A.K., Dubey, B., Goel, S., Bhattacharya, J., 2020. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. Resour. Conserv. Recycl. 162, 105052. https://doi.org/10.1016/j.resconrec.2020.105052.

Sharma, H.B., Vanapalli, K.R., Samal, B., Cheela, V.R.S., Dubey, B.K., Bhattacharya, J., 2021. Circular economy approach in solid waste management system to achieve UN-SDGs: solutions for post-COVID recovery. Sci. Total Environ. 800, 149605. https://doi.org/10.1016/J.SCITOTENV.2021.149605.

Staub, C., 2020a. Recycled Fiber Operations Shut Down - Resource Recycling [WWW Document]. Resour. Recycl. Inc. https://resource–recycling-com.cdn.ampproject.org/c/s/resource-recycling.com/recycling/2020/06/09/recycled-fiber-operations-shut-down/amp/. (Accessed 15 June 2021).

Staub, C., 2020b. City data shows COVID-19 impacts on recycling tonnages - resource recycling [WWW document]. Resour. Recycl. Inc. https://resource-recycling.com/recycling/2020/04/28/city-data-shows-covid-19-impacts-on-recycling-tonnages/. (Accessed 13 March 2021).

Suresh, R., Logue, R.J., Gotur, D.B., Hsu, S.H., 2022. COVID-19: A health-care worker's perspective. COVID-19 Pandemic. Elsevier, pp. 53–70 https://doi.org/10.1016/B978-0-323-82860-4.00018-5.

Tabatabaei, M., Hosseinzadeh-Bandbafha, H., Yang, Y., Aghbashlo, M., Lam, S.S., Montgomery, H., Peng, W., 2021. Exergy intensity and environmental consequences of the medical face masks curtailing the COVID-19 pandemic: malign bodyguard? J. Clean. Prod. 313, 127880. https://doi.org/10.1016/J.JCLEPRO.2021.127880.

Tassakka, M.I.S., Musrianton, M., Alsita, I., Runtu, K.G.A., Normayasari, Ndahawali, D.H., 2020. Modeling the impact of the COVID-19 pandemic on air emissions indicators of climate change originating from solid waste management in coastal settlements. IOP Conference Series: Earth and Environmental Science. IOP Publishing Ltd https://doi.org/10.1088/1755-1315/584/1/012062.

Tirkolaee, E.B., Aydın, N.S., 2021. A sustainable medical waste collection and transportation model for pandemics. Waste Manag. Res., 734242X211000437 https://doi.org/10.1177/0734242X211000437.

Tirkolaee, E.B., Abbasian, P., Weber, G.-W., 2021. Sustainable fuzzy multi-trip location-routing problem for medical waste management during the COVID-19 outbreak. Sci. Total Environ. 756, 143607. https://doi.org/10.1016/j.scitotenv.2020.143607.

Torres, F.G., De-la-Torre, G.E., 2021. Face mask waste generation and management during the COVID-19 pandemic: an overview and the Peruvian case. Sci. Total Environ. 786, 147628. https://doi.org/10.1016/j.scitotenv.2021.147628.

Tripathi, A., Tyagi, V.K., Vivekanand, V., Bose, P., Suthar, S., 2020. Challenges, opportunities and progress in solid waste management during COVID-19 pandemic. Case Stud. Chem. Environ. Eng. 2, 100060. https://doi.org/10.1016/j.cscee.2020.100060.

Tsukiji, M., Gamaralalage, P.J.D., Pratomo, I.S.Y., Onogawa, K., Alverson, K., Honda, S., Ternald, D., Dilley, M., Fujioka, J., Condrorini, D., 2020. Waste Management During the COVID-19 Pandemic From Response to Recovery, UNEP-IETC. United Nations Environment Programme, Institute for Global Environmental Strategies, Japan.

UNEP, 2021. Healthcare waste: what to do with it? [WWW document]. United Nations Environ. Program . https://www.unep.org/news-and-stories/story/healthcare-waste-what-do-it. (Accessed 13 June 2021).

Urban, R.C., Nakada, L.Y.K., 2021. COVID-19 pandemic: solid waste and environmental impacts in Brazil. Sci. Total Environ. 755, 142471. https://doi.org/10.1016/j.scitotenv.2020.142471.

Valizadeh, J., Mozafari, P., 2021. A novel cooperative model in the collection of infectious waste in COVID-19 pandemic. J. Model. Manag. https://doi.org/10.1108/JM2-07-2020-0189.

Valizadeh, J., Hafezalkotob, A., Seyed Alizadeh, S.M., Mozafari, P., 2021. Hazardous infectious waste collection and government aid distribution during COVID-19: a robust mathematical leader-follower model approach. Sustain. Cities Soc. 69, 102814. https://doi.org/10.1016/j.scs.2021.102814.

Vanapalli, K.R., Sharma, H.B., Ranjan, V.P., Samal, B., Bhattacharya, J., Dubey, B.K., Goel, S., 2021. Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. Sci. Total Environ. 750, 141514. https://doi.org/10.1016/j.scitotenv.2020.141514.

Vidal-Mones, B., Barco, H., Diaz-Ruiz, R., Fernandez-Zamudio, M.-A., 2021. Citizens' Food Habit Behavior and Food Waste Consequences during the First COVID-19 Lockdown in Spain. 2021Sustain. 13 (13), 3381. https://doi.org/10.3390/SU13063381 3381.

Vu, H.L., Ng, K.T.W., Richter, A., Kabir, G., 2021a. The use of a recurrent neural network model with separated time-series and lagged daily inputs for waste disposal rates modeling during COVID-19. Sustain. Cities Soc. 75, 103339. https://doi.org/10.1016/J.SCS.2021.103339.

Vu, H.L., Ng, K.T.W., Richter, A., Karimi, N., Kabir, G., 2021b. Modeling of municipal waste disposal rates during COVID-19 using separated waste fraction models. Sci. Total Environ. 789, 148024. https://doi.org/10.1016/J.SCITOTENV.2021.148024.

Wang, Jiao, Shen, J., Ye, D., Yan, X., Zhang, Y., Yang, W., Li, X., Wang, Junqi, Zhang, L., Pan, L., 2020. Disinfection technology of hospital wastes and wastewater: suggestions for disinfection strategy during coronavirus disease 2019 (COVID-19) pandemic in China. Environ. Pollut. 262, 114665. https://doi.org/10.1016/j.envpol.2020.114665.

Wang, J., Chen, Zhuqi, Lang, X., Wang, S., Yang, L., Wu, X., Zhou, X., Chen, Zhulei, 2021. Quantitative evaluation of infectious health care wastes from numbers of confirmed, suspected and out-patients during COVID-19 pandemic: a case study of Wuhan. Waste Manag. 126, 323–330. https://doi.org/10.1016/J.WASMAN.2021.03.026.

Weber, C.T., Ranzan, L., Liesegang, L.L.M., Trierweiler, L.F., Trierweiler, J.O., 2020. A circular economy model for ethanol and alcohol-based hand sanitizer from sweet potato waste in the context of COVID-19. Braz. J. Oper. Prod. Manag. 17, 1–12. https://doi.org/10.14488/bjopm.2020.028.

WHO, 2020. Transmission of SARS-CoV-2: Implications for Infection Prevention Precautions [WWW Document]. World Heal. Organ. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions. (Accessed 4 April 2021).

WHO, 2021. WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data [WWW Document]. World Heal. Organ. https://covid19.who.int/. (Accessed 13 May 2021).

Yang, L., Yu, X., Wu, X., Wang, J., Yan, X., Jiang, S., Chen, Z., 2021. Emergency response to the explosive growth of health care wastes during COVID-19 pandemic in Wuhan, China. Resour. Conserv. Recycl. 164, 105074. https://doi.org/10.1016/j.resconrec.2020.105074.

Yao, S., 2021. Fuzzy-based multi-criteria decision analysis of environmental regulation and green economic efficiency in a post-COVID-19 scenario: the case of China. Environ. Sci. Pollut. Res. 1–27. https://doi.org/10.1007/s11356-021-12647-w.

Yousefi, M., Oskoei, V., Jonidi Jafari, A., Farzadkia, M., Hasham Firooz, M., Abdollahinejad, B., Torkashvand, J., 2021. Municipal solid waste management during COVID-19 pandemic: effects and repercussions. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-021-14214-9.

Yu, H., Sun, X., Solvang, W.D., Zhao, X., 2020. Reverse logistics network design for effective management of medical waste in epidemic outbreaks: insights from the coronavirus disease 2019 (COVID-19) outbreak in Wuhan (China). Int. J. Environ. Res. Public Health 17, 1770. https://doi.org/10.3390/ijerph17051770.

Zand, A.D., Heir, A.V., 2020. Emerging challenges in urban waste management in Tehran, Iran during the COVID-19 pandemic. Resour. Conserv. Recycl. 162, 105051. https://doi.org/10.1016/j.resconrec.2020.105051.

Zand, A.D., Heir, A.V., 2021a. Emanating challenges in urban and healthcare waste management in Isfahan, Iran after the outbreak of COVID-19. Environ. Technol. 42, 329–336. https://doi.org/10.1080/09593330.2020.1866082.

Zand, A.D., Heir, A.V., 2021b. Environmental impacts of new coronavirus outbreak in Iran with an emphasis on waste management sector. J. Mater. Cycles Waste Manag. 23, 240–247. https://doi.org/10.1007/s10163-020-01123-1.

Zhang, F., Cao, C., Li, C., Liu, Y., Huisingh, D., 2019. A systematic review of recent developments in disaster waste management. J. Clean. Prod. 235, 822–840. https://doi.org/10.1016/j.jclepro.2019.06.229.

Zhao, X., You, F., 2021. Waste respirator processing system for public health protection and climate change mitigation under COVID-19 pandemic: novel process design and energy, environmental, and techno-economic perspectives. Appl. Energy 283, 116129. https://doi.org/10.1016/j.apenergy.2020.116129.

Zhou, C., Yang, G., Ma, S., Liu, Y., Zhao, Z., 2021. The impact of the COVID-19 pandemic on waste-to-energy and waste-to-material industry in China. Renew. Sust. Energ. Rev. 139, 110693. https://doi.org/10.1016/j.rser.2020.110693.