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An update of COVID-19 influence on waste management

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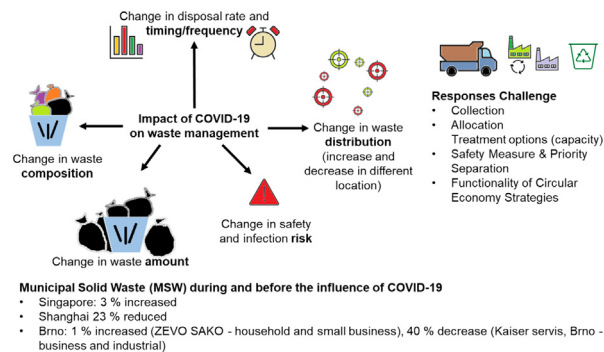
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HIGHLIGHTS

- The influence of COVID-19 on waste management is summarised.
- Manual sorting and recycling are restricted due to the potential risk of infection.
- Shanghai shows a 23% reduction in MSW and 3% increase in Singapore.
- Brno demonstrates 1% increase for MSW from household and small business, 40% decrease for business and industrial.
- The impacts of COVID-19 can be diverse depending on the geographical and sociological factors.

GRAPHICAL ABSTRACT



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ABSTRACT

COVID-19 has been sweeping the world. The overall number of infected persons has been increased from 5 M in March 2020 to over 22 M in August 2020 and growing, which seems not to get its peak at the current stage. This has contributed to waste generation and different phases of challenges in waste management practices. The impacts including change in waste amount, composition, timing/frequency (temporal), distribution (spatial) and risk, which affects the handling and treatment practices. Recent impacts, challenges and developments on waste management in the response of COVID-19 have been assessed in this update. Singapore, the cities of Shanghai in China and Brno in the Czech Republic (a member state of the European Union), representing different pandemic development situation and also various cultural attitudes, are specifically analysed and discussed with current data. However, it should be noted that it is still fast developing. A varying trend in term of the waste amount is identified. Shanghai is showing a ~23% decline in household waste amount; however, Singapore is showing a ~3% increase, and Brno is showing a ~1% increase in household waste amount but ~40% decline in business and industrial waste. Manual sorting and recycling have been reported as restricted due to safety precaution. This is supported by the interview communication with ZEVO SAKO (the largest incineration plant in the Czech Republic). This study highlighted that the practices or measures at each place could serve as a guideline and reference. However, adaption is required according to the geographical and socioeconomic factors.

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1. Introduction

The paper presented by Klemeš et al. (2020a) in March based on that time experience assumed that waste management would follow the

curves shown in Fig. 1. This paper has received considerable attention even in online news outlets. Regions, countries and cities worldwide are allocating resources actively to prevent, control or contain COVID-19. However, it should be noted that although facing the same crisis, the situation, measures taken and effectiveness in each region can be attentively diverse. The countries and their governments reacted in various ways and timing to adopt restrictive measures – from very strict

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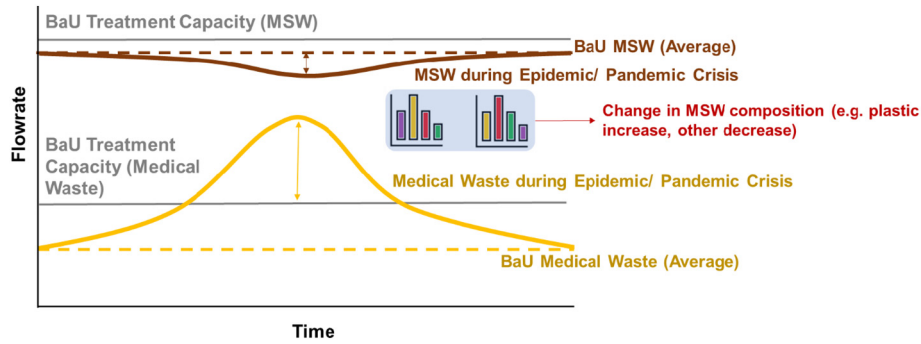


Fig. 1. The expected trend of medical waste and MSW. Adapted from Klemeš et al. (2020a).

closure to mild suggestions. A typical controversy appeared is the wearing of protective masks, especially at the beginning of the pandemic. In some countries, it is advised only for the citizen who is sick or very vulnerable. The use of masks by ordinary citizens became controversial due to the lack of correct handling and disposal, and the shortage in healthcare facilities (World Health Organization, 2020). It is suggested that masks (e.g. N95) should be reserved for frontline workers, for example, doctors. Fig. 1 shows the prediction that the overall municipal solid waste (MSW) generation would slightly decrease during COVID-19. However, it depends on location, and it can happen that there is a change in composition where some of the waste fractions are increased while the other decreased. For example, it is still early to summarise the overall plastic usage is spike during the pandemic without the support of statistics. A considerable increase in plastic usage has been related to requirements packaging, and single-use items related to the demand for food/goods delivery and take out. Plastics demand for medical purposes has considerably increased. However, especially during the lockdown, the plastic demand of, e.g. transport, construction, leisure etc. dropped in line with the decreased production and usage.

Fig. 2 summarises the impacts of COVID-19 on waste management. These include the change in waste composition, waste amount, disposal frequency and timing (temporal), distribution (spatial) and infection risk. The waste handling precaution and adaption of different countries have been summarised by (ACR+, 2020). Dynamic and responsive measures are required to overcome the unprecedented challenges. For

example, waste collection and allocation have to be adjusted due to the changes in waste amount and composition. The existing collection system, both frequency and route, could be altered by the waste collection demand at different places and different timing. It is restricted to the existing treatment facilities and capacity, which may or may not ready to adapt to this sudden change. For example, it is reported that the medical waste in China (Hubei Province) increased by 600% from 40 t/d to 240 t/d (ADB, 2020a), overwhelming existing medical transport and disposal infrastructure. Based on the list of considerations and recommendation by ADB (2020a), medical incinerators, medical autoclaves and sanitary landfills are used to deal with the pandemic waste amount. Mobile incinerators, industrial furnaces and cement kilns could be considered when the existing system is overloaded. It is possible to refer to Klemeš et al. (2020a) for more details on the configuration. ADB (2020a) also suggested that the collection frequency of MSW has to be rescheduled to reallocate available assets and workforce for infectious medical waste management. A circular economy, which prioritised refrain, reuse and recycle etc. (Reike et al., 2018), is one of the waste management approaches, which has been affected by COVID-19. It is a difficult decision whether to avoid or to continue, e.g. recycling, during this crisis. Recycling could expose the worker to the risk of infection. Resource Recycling, Inc (2020) reported that the coronavirus pandemic has been impacting the US recycling programs since mid-March when widespread stay-at-home orders and other regulations began to transform daily life across the country. The recycling

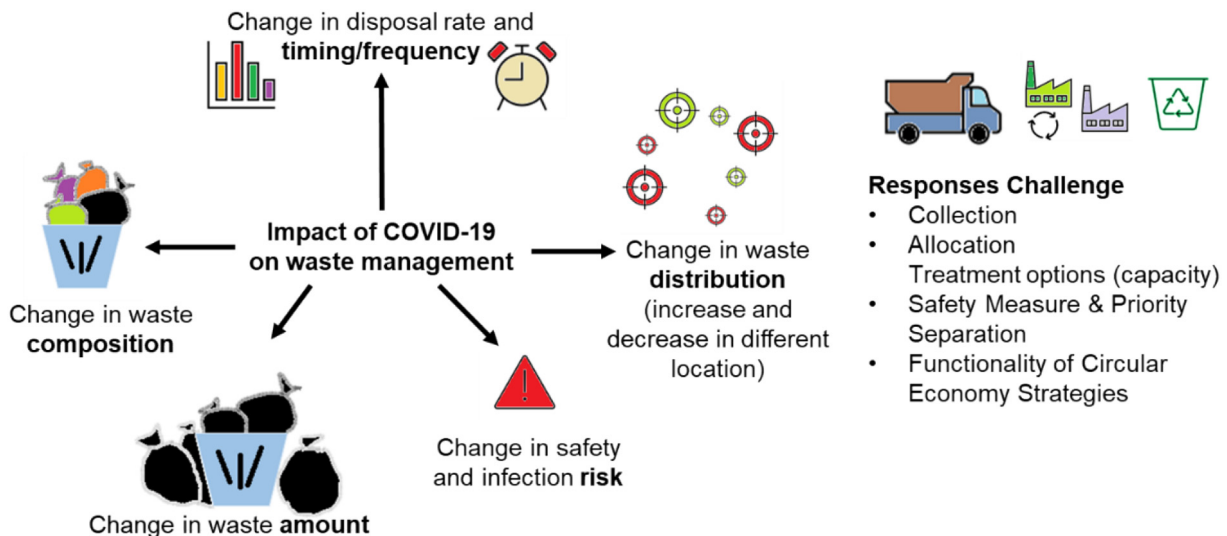


Fig. 2. Impacts and challenges of COVID-19 on waste management.

sector faced material volume changes and operational impacts to accommodate safety measures, at times leading programs to suspend services. If recycling should be avoided in this current stage, how long should this emergence measure needs to be in place remains another open question. Is there an optimal solution where recycling can be conducted safely, with precautions, through the understanding of the virus survival on the different materials? The study by Chin et al. (2020), declared that the virus is not detected on the glass and banknote from day 4, stainless steel and plastic from day 7 while it is still detectable on a surgical mask on day 7. However, the identified timing still needs more studies, as it can be influenced by the surrounding condition.

In some countries, all municipal waste has been treated as non-recyclable and send for incineration or sanitary landfill during this critical period (ADB, 2020a). At this current stage, where the understanding of the COVID-19 is still limited, at most of the time, better safe than sorry has been the chosen approach. However, it is still important to minimise the environmental impacts of waste management, as much as possible, even when the highest preferable options in waste management and circular economy hierarchy cannot be followed. From March 2020 various parts of the world experienced development closely related to a pandemic situation. During the closure and declared state of the emergency, the main focus was to minimise the infection. This had been developed step by step when authorities were gaining the experience and later tried to make relaxations to recover the business and consumption by the population. This study aims to summarise the potential challenges of waste management during and in post-pandemic stages where the situation in Singapore, Shanghai (China) and Brno (the Czech Republic) are particularly assessed. The identified challenges and research gaps in this study could facilitate strategy development and operational research.

2. COVID-19 related waste management in different regions

A comprehensive analysis worldwide would consume considerable time, and the situation is still developing and changing fast. An initial analysis has been attempted for three regions, Singapore (a city-country), Shanghai (the economic centre and megacity in China) and Brno in the Czech Republic (part of the European Union), representing different pandemic development situation and also various cultural attitudes. Table 1 shows basic information about the three regions. Based on the to-date record (published on 17 August 2020), the total cases/1 M population in Singapore were 9765, in Shanghai 31 and in Brno 57.

2.1. Singapore, a city-country

This is a specific case of a country substitute by a large city, highly international and base of the world trade. The population has been 5.7 M (DSS, 2019). By 15 August, 55,661 COVID-19 cases are confirmed in Singapore (MOH, 2020). As a highly international country, Singapore

was one of the first countries that were attacked by the second-wave disease outbreak at the beginning of April 2020 (Jiang et al., 2020a). As much as the data have been available, the waste and namely plastic waste management have been developing as follows.

Before the pandemic, statistical data have shown that the overall recycling rate was about 60% (in the recent two years in Fig. 3a, including construction waste), and the plastic recycling rate is just 4% in the same period (Fig. 3b). Although the overall trend of plastic waste amount has been increasing, the plastic recycling rate keeps a descending trend (i.e. 11% in 2013 to 4% in 2019). Such a low recycling rate is attributed to the complicated nature of plastic waste mixtures and the presence of impurities, which makes mechanical recycling in Singapore inefficient (Khoo, 2019). Although the recycling rate is quite low for plastic, the total disposal rate of plastic waste is over 96% in 2019 (NEA, 2020a). Singapore has developed mature energy recovery systems. Most of the plastic waste was transferred by incineration to promote the waste-to-energy programme. Under a zero-waste masterplan, the government aims to elevate the non-domestic recycling rate from 74% in 2018 to 81% by 2030 and elevate the domestic recycling rate from 22% in 2018 to 30% by 2030 (Hicks, 2019). The zero-waste masterplan offers steps on how to achieve a target of ~30% waste reduction by 2030 to extend the lifespan of Semakau Landfill to 2035 (Tan, 2019). The turning trend of MSW generation in Fig. 3a does offer confidence for achieving the waste reduction objective.

The disease pandemic brought challenges for waste management in Singapore as well. Compared with March 2020, the average daily waste amount collected increased by 3% in the circuit breaker period from 7 April to 1 June 2020 (Low and Koh, 2020). According to the estimation based on an online survey on 1110 respondents, Singapore households produced extra 1334 t of plastic waste (e.g. disposable forks, containers and spoons) in the circuit breaker period (Low and Koh, 2020). The meal delivery was estimated to have an increase of 73% during the eight weeks (Low and Koh, 2020). Collectively, the low recycling rate of plastic waste in recent years and the surge of plastic waste during disease pandemic make sustainable waste management difficult to maintain. The elevation of the total waste amount in Singapore during COVID-19 outbreak has been hindering the zero-waste masterplan and circular economy. To cope with the challenge in sustainable waste management during disease pandemic, the National Environment Agency (NEA) of Singapore designed tripartite advisory and recommendations for COVID-19 waste management. Details of the tripartite advisory are referred to NEA (2020b).

2.2. Shanghai, a megacity in China

Shanghai is a huge business and residential centre in China, with a population just above 27 M inhabitants (WPR, 2020). By 15 August 2020, there were 825 confirmed cases, including 379 imported cases, reported in Shanghai (SMHC, 2020). This reflects a surprising prevention and control effect for such a megacity. It was noted that, on 9 May 2020, Shanghai returned the response level of major public health emergencies from the second level (tough) to the third level (slight). Shanghai government made great effects in improving sustainable waste management. With rapid population growth, the annual solid waste generation in Shanghai was increased by over six times from 1978 to 2010 (Jiang and Liu, 2016). Since 2011, Shanghai started to put waste segregation into government core projects (Yu, 2020). To enhance waste segregation and recycling, a new waste dumping mode with both policy and incentive interactions, as reported by Jiang et al. (2020b), was developed in Shanghai in 2018 and 2019. Associated with the new mode, the WeChat social media was employed to enhance household waste management in Shanghai (Jiang et al., 2021). By mid-June 2020, the statistical data (Yu, 2020) of the four category waste is updated (Fig. 4) as follows: the collected amount of recyclables in the Great Shanghai area was 6813.7 t/d with an increasing rate of 71.1% compared to the same period in 2019. The sorted amount of hazardous

Table 1
Basic information about the three regions.

Country/city	Location	Population	Confirmed cases	Total cases/1 M population
Singapore	1°17'N, 103°50'E	~5.7 M	55,661 ^a	9765
Shanghai	31°13'43"N, 121°28'29"E	~27 M	825 ^b	31
Brno	49°12'N, 16°37'E	~10.7 M	613 ^c	57

Notes: The statistics are based on the available data published on 17 August 2020; there is a delay due to validation of records.

^a Data from Ministry of Health (MOH), Singapore (MOH, 2020) by 15 August 2020.

^b Data from Shanghai Municipal Health Commission (SMHC, 2020) by 15 August 2020.

^c Data from Ministry of Health of the Czech Republic (2020), by 14 August 2020.



Fig. 3. Waste generation and its recycling rate from 2003 to 2019 in Singapore. (a) Total solid waste and overall recycling rate; (b) total plastic waste and plastic recycling rate. Data from NEA (2020a).

waste was 3.3 t/d with 11.2 times increase. The sorted amount of wet waste (i.e. biodegradable food waste) was 9632.1 t/d with a growth rate of 38.5%. The sorted amount of dry waste disposal was 15,518.2 t/d with a reduced rate of 19.8%. These statistical data indicate that the segregation and recycling effect grown significantly from 2019 to 2020.

During the COVID-19 pandemic, although waste segregation and recycling behaviours seemed to be not influenced significantly (Chen, 2020), the well functional waste management system was disrupted to some extent. In March 2020, Shanghai collected 3342 t/d recyclables, disposed 11,693 t/d dry waste and segregated 7394 t/d wet waste (Chen, 2020). Compared to the average daily waste generation in 2019 (Fig. 5), the reduction rate of the average daily amount in March 2020 was calculated as 23.2%. A similar waste reduction rate (i.e. about 30%) in major cities of China during disease pandemic was reported by Klemeš et al. (2020a). But this is not the case in Singapore (i.e. a 3% increase during the circuit breaker period). Although a noticeable reduction in waste was observed in Shanghai, the severe shortage in resources and workforce caused by virus-prevention measures (Bloomberg, 2020) hinder the full implementation of sustainable waste management that introduced and enforced in 2019. This kind of uncertain waste amount reduction during the COVID-19 pandemic would also bring challenges to the incineration system for dry waste and the biodegradable system for wet waste since waste-to-energy systems favour stable waste supply rather than supply with uncertain fluctuations.

Another potential challenge lies in the recovery ability of waste management during the post-disease pandemic. Compared to 2019 (before pandemic) and March 2020 (during the pandemic) as shown in Fig. 5, the growth rates of the average daily amount in mid-June 2020 are calculated as 8.5% and 29.8%. During the several months after disease pandemic, the consumption behaviours relying on more

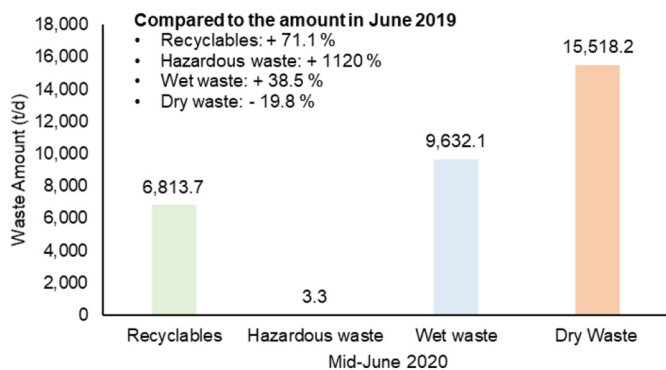


Fig. 4. The changes in the waste amount in Shanghai in mid-June 2020 compared to June 2019. Data from Yu (2020).

disposable plastic containers are challenging to change, and the residents' engagement in waste management is hard to restore due to the panic on disease outbreak (Chen, 2020). Collectively, they could exacerbate the challenge in the recovery ability of waste management.

2.3. The City of Brno in the Czech Republic, part of the European Union

The complete Czech Republic (CZ) has a population around 10.7 M inhabitants, the City of Brno around 400,000, and with its residential hub close to 1 M. The CZ is served by just four main incineration plants and Brno Incinerator is a substantial one. ZEVO SAKO with a capacity of 248,000 t/y is the largest incineration plant in the CZ, accounting for 32% of the national capacity. 98% of the mixed municipal waste is processed and could produce more than 50,000 MWh/y of electricity and supplies 1,000,000 GJ of heat to Brno households with capacity reserved. Compared to Singapore, the infection of COVID-19 cases in Brno is relatively less. To date (data by 14 August, published on 17 August 2020), the cumulative cases in the CZ are 18,610, where 613 is from Brno. Despite lower in a number of cases, the pandemic is still having impacts on the waste management practice in Brno, especially when ZEVO SAKO is serving beside Brno also the various mostly surrounding region in the CZ. Fig. 6a shows the collected waste amount in ZEVO SAKO. The waste amount is generally consistent in 2019 and 2020 without distinct increasing or reducing. However, it is still visible that there is an increase in waste amount during the initial implementation of lockdown (March 2020). The waste amount decreased in April and May 2020 and increased when the restriction measure started to lift. There is a 39% decrease in waste amount when considering the information by another waste service provider (Fig. 6b). More detail assessment is needed by

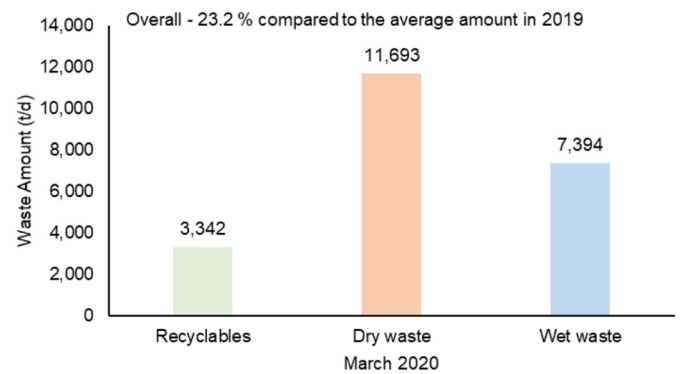


Fig. 5. The changes in the waste amount in Shanghai in March 2020 compared to the average daily amount in 2019. Data from Chen (2020).

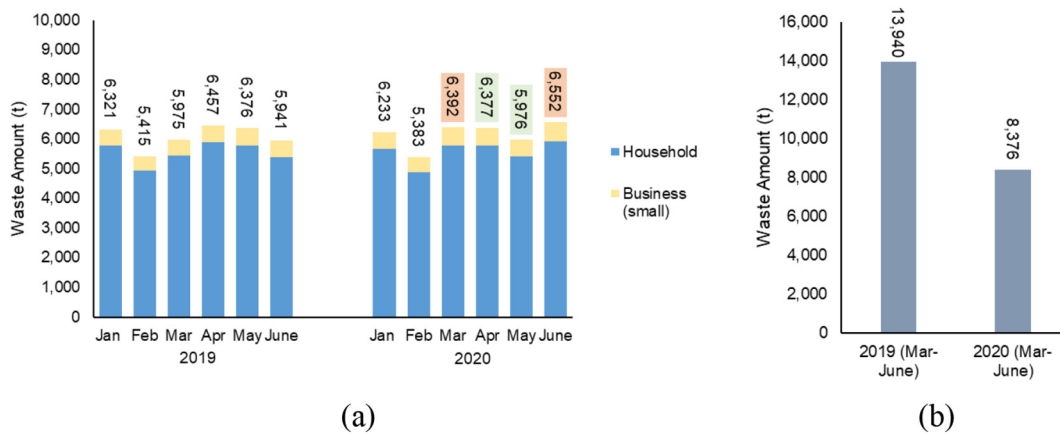


Fig. 6. The municipal solid waste amount handled by (a) ZEVO SAKO in 2019 and 2020 and (b) Kaiser Service. (However, there are the other handler companies, FCC, specialising on businesses and industry).

comparing to the previous years and especially the changes in waste composition in the future. Based on the interview conducted with ZEVO SAKO, the operation of the paper and plastic sorting line stops due to the potential of infection. The other proactive measures which are taken including reduce the number of crews of garbage trucks and complied a replacement shift of the control room.

3. Structural changes and the other indirect impacts

There have been various studies reported the environmental benefit arises from the lockdown or restriction of human activities due to the COVID-19. The CO₂ (Le Quér et al., 2020), PM_{2.5} (Sharma et al., 2020) and NO_x (NASA, 2020), have been reported as reduced. As highlighted by Dente and Hashimoto (2020), the pandemic induced positive and negative outcomes. More studies are needed to fully understand the overall environmental impacts as some could be only temporary. Huang et al. (2020) indicated that a coordinated and balanced strategy for controlling multiple pollutants is needed as a high reduction in primary pollutants could stimulate the formation of secondary pollution. It should also be noted that the environmental impacts from hospitals (Eckelman et al., 2018) including the disposal of PPE, test kits and other medical waste as well as the consumption of resources or utility are yet to be accounted comprehensively. Klemeš et al. (2020c) roughly estimated the extra energy and environmental footprints of PPE, testing kits and disinfectants used for COVID-19 fighting, and appealed to the environmental awareness during and after the pandemic. The other impacts of COVID-19 include the energy sector (Abu-Rayash and Dincer, 2020) and supply chains or trading networks. The energy demand and price etc. would indirectly affect the feasibility of waste to energy recovery. The PPE supply chain bottlenecks (ADB, 2020b) due to the spike in demand, trade restrictions, shortage of materials (distribution of supplier and manufacturing in different countries) could probably attract the attention of policymaker to seek for a future solution, in the post-pandemic period. However, it highly depends on the priority in the post-COVID-19 economy. For example, the implementation of recycling would be more challenging if the incentives for green initiatives are reduced in the post-COVID-19 economy. An issue is that legislations can be politically driven and may be difficult to change. On the contrary, emergency situations can accelerate revisions of flawed regulations.

4. Future outlook

In the early stage of the disease pandemic, researchers have made some preliminary judgements on the COVID-19 influence/impacts on the environment and waste management based on limited data available. Chakraborty and Maity (2020) concluded that “the pandemic

created a very positive impact on the world environment”. However, the result of this presented study suggests the overall impacts are yet to be evaluated and is not as positive as proposed. As an example, in the waste management field, the potential negative impacts are not instantaneous, but it starts to be apparent as the COVID 19 situation starts to have better control. The necessary adaptations arising from the changes of lifestyle in behaviour are yet to be assessed. Despite all the unpleasant aftermath, COVID-19 highlights the shortcoming and the potential improvement in term of responsive to an emergency in the current waste management system. Several outlooks are offered based on the outcomes of this study.

- i. A longer-term systematic assessment is required to understand the lasting impact on waste management systems and environmental sustainability. This study has provided some insights and current data of three representative regions. A broader scope of regions worldwide can facilitate the correlation study in developing a comprehensive understanding and decision making.
- ii. A flexible waste treatment design and planning could enhance the rigidity of the waste management system in overcoming a similar crisis or disease outbreak. Mobile, decentralised, smart (e.g. Internet of Things, IoT) and adaptable (different feedstock) treatment approaches are worth more research attention. The crisis could serve as an opportunity to revise and improve the existing waste management system.
- iii. The consciousness training and psychological reconstruction of residents and managers are important to restore and enhance the engagement of society in waste management in the new norms period or after the COVID-19 pandemic, especially the 10Rs practices for MSW (Reike et al., 2018) as well as the consciousness and management for plastics (Klemeš et al., 2020b).

5. Conclusions

The pandemic is still far from the over, and it cannot be sure that the future waves would confront any part of the world or state. What has been a positive experience is that, even when it seems we are still in uncertainty about safe and efficient vaccine development, the world is getting experience how to cope with various related challenges. Approaching the peak of the pandemic, the waste management had not been receiving the priority which is needed to minimise the harmful effect on the environment. Despite facing the same crisis, the situation, challenges, measures, and effectiveness in each place could be diverse. The collected information shows a variable trend on the decreasing or increasing in waste amount. MSW in Shanghai is reduced by 23.2%, but in Singapore, it is increased by 3%. The MSW increment or

decrement in Brno (ZEVO SAKO) is not obvious where the increment is 1% by considering the changes in Jan-June. However, the waste amount of another service provider (Kaiser servis, Brno) covering another part of the region and services shows 40% decrement. This short communication has been an attempt to gather even so far short-term experience for helping to progress waste management issues. In the midst of every crisis, lies great opportunity – Albert Einstein. The crisis could serve as an opportunity to restructure and enhance the robustness of the waste management system if well managed. The MSW amount and management issues reported in this study has been focused on Singapore, Shanghai and Brno. A comprehensive assessment considering wider regions, preferable globally, is needed for a more conclusive understanding towards better management during a similar crisis.

CRedit authorship contribution statement

Yee Van Fan: Conceptualisation, Original draft, Writing-revising and editing, Data Curation, Visualisation. **Peng Jiang:** Conceptualisation, Original draft, Data collection (Singapore, Shanghai) and curation, Writing-revising and editing. **Jiří Jaromír Klemes:** Conceptualisation, Original draft, Supervision, Writing-revising and editing, Funding Acquisition. **Milan Hemzal:** Data Collection (Brno), Conducting interviews.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abu-Rayash, A., Dincer, I., 2020. Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. *Energy Res. Soc. Sci.* 101682.

ACR+ (Association of Cities and Regions for Sustainable Resource Management), 2020. Municipal waste management and COVID-19. www.acrplus.org/en/municipal-waste-management-covid-19 (accessed 16.08.2020).

ADB, 2020a. Managing infectious medical waste during the COVID-19 pandemic. www.adb.org/sites/default/files/publication/578771/managing-medical-waste-covid19.pdf. (Accessed 8 July 2020).

ADB, 2020b. Global shortage of personal protective equipment amid COVID-19: supply chains, bottlenecks, and policy implications. www.adb.org/sites/default/files/publication/579121/ppe-covid-19-supply-chains-bottlenecks-policy.pdf. (Accessed 7 August 2020).

Bloomberg, 2020. China’s war on garbage faces a major coronavirus setback. www.bloombergquint.com/business/china-s-war-on-garbage-faces-a-major-coronavirus-setback. (Accessed 7 June 2020).

Chakraborty, I., Maity, P., 2020. COVID-19 outbreak: migration, effects on society, global environment and prevention. *Sci. Total Environ.* 728, 138882.

Chen, X., 2020. Did Shanghai’s garbage segregation deteriorate during the COVID-19 pandemic? The latest “monthly report” says like this. www.jfdaily.com/news/detail?id=237811. (Accessed 7 June 2020).

Chin, A., Chu, J., Perera, M., Hui, K., Yen, H.L., Chan, M., Peiris, M., Poon, L., 2020. Stability of SARS-CoV-2 in different environmental conditions. *The Lancet Microbe* 1 (1), E10.

Dente, S.M.R., Hashimoto, S., 2020. COVID-19: A pandemic with positive and negative outcomes on resource and waste flows and stocks. *Resour. Conserv. Recycl.* 161, 104979.

DSS, 2019. Population Trends, 2019. Department of Statistics Singapore (DSS) www.singstat.gov.sg/publications/population/population-trends. (Accessed 7 October 2020).

Eckelman, M.J., Sherman, J.D., MacNeill, A.J., 2018. Life cycle environmental emissions and health damages from the Canadian healthcare system: an economic-environmental-epidemiological analysis. *PLoS Med.* 15 (7), e1002623.

Hicks, R., 2019. Singapore’s zero-waste plan aims to raise domestic recycling rate from 22 to 30 per cent by 2030. www.eco-business.com/news/singapores-zero-waste-plan-aims-to-raise-domestic-recycling-rate-from-22-to-30-per-cent-by-2030/. (Accessed 7 June 2020).

Huang, X., Ding, A., Gao, J., Zheng, B., Zhou, D., Qi, X., Tang, R., Wang, J., Ren, C., Nie, W., Chi, X., Xu, Z., Chen, L., Li, Y., Che, F., Pang, N., Wang, H., Tong, D., Qin, W., Cheng, W., Liu, W., Fu, Q., Liu, B., Chai, F., Davis, S.J., Zhang, Q., He, K., 2020. Enhanced secondary pollution offset reduction of primary emissions during COVID-19 lockdown in China. *Natl. Sci. Rev.* nwa137 <https://doi.org/10.1093/nsr/nwaa137>.

Jiang, P., Liu, X., 2016. Hidden Markov model for municipal waste generation forecasting under uncertainties. *Eur. J. Oper. Res.* 250 (2), 639–651.

Jiang, P., Fu, X., Fan, Y.V., Klemes, J.J., Chen, P., Ma, S., Zhang, W., 2020a. Spatial-temporal potential exposure risk analytics and urban sustainability impacts related to COVID-19 mitigation: a perspective from car mobility behaviour. *J. Clean. Prod.* <https://doi.org/10.1016/j.jclepro.2020.123673>.

Jiang, P., Fan, Y.V., Zhou, J., Zheng, M., Liu, X., Klemes, J.J., 2020b. Data-driven analytical framework for waste-dumping behaviour analysis to facilitate policy regulations. *Waste Manag.* 103, 285–295.

Jiang, P., Fan, Y.V., Klemes, J.J., 2021. Data analytics of social media publicity to enhance household waste management. *Resour. Conserv. Recycl.* 164, 105146.

Khoo, H.H., 2019. LCA of plastic waste recovery into recycled materials, energy and fuels in Singapore. *Resour. Conserv. Recycl.* 145, 67–77.

Klemes, J.J., Fan, Y.V., Tan, R.R., Jiang, P., 2020a. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renew. Sust. Energy Rev.* 127, 109883.

Klemes, J.J., Fan, Y.V., Jiang, P., 2020b. Plastics: friends or foes? The circularity and plastic waste footprint. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* <https://doi.org/10.1080/15567036.2020.1801906>.

Klemes, J.J., Fan, Y.V., Jiang, P., 2020c. The energy and environmental footprints of COVID-19 fighting measures – PPE, disinfection, supply chains. *Energy*, 118701 <https://doi.org/10.1016/j.energy.2020.118701>.

Le Qué, C., Jackson, R.B., Jones, M.W., Smith, A.J., Abernethy, S., Andrew, R.M., De Gol, A.J., Willis, D.R., Shan, Y., Canadell, J.G., Friedlingstein, P., Creutzig, F., Peters, G.P., 2020. Temporary reduction in daily global CO₂ emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* 10, 647–653.

Low, D.W., Koh, A., 2020. Singapore’s food delivery surge during lockdown highlights waste problems. www.bloomberg.com/news/articles/2020-06-24/singapore-binges-on-plastics-ordering-food-during-virus-lockdown. (Accessed 7 June 2020).

Ministry of Health of the Czech Republic (Ministerstvo instead of Ministerstva), 2020. COVID-19: overview of persons with laboratory-proven COVID-19 disease according to reports from regional hygienic stations (validated data) onemocneni-aktualne.mzcr.cz/covid-19/prehledy-khs accessed 10.07.2020.

MOH, 2020. COVID-19 Situation Report. Ministry of Health (MOH), Singapore [covid19.gov.sg/](https://www.covid19.gov.sg/). (Accessed 7 October 2020).

NASA, 2020. NASA Satellite data show 30 percent drop in air pollution over northeast U.S. www.nasa.gov/feature/goddard/2020/drop-in-air-pollution-over-northeast. (Accessed 7 June 2020).

NEA, 2020a. Waste statistics and overall recycling, National Environment Agency (NEA). www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling. (Accessed 7 June 2020).

NEA, 2020b. Tripartite Advisory on Ensuring Sustainability of the Waste Management Sector in View of COVID-19. National Environment Agency (NEA). <[www.nea.gov.sg/docs/default-source/our-services/public-cleanliness/covid-19/tripartite-advisory-for-wm-industry-\(covid-19\)_20200525.pdf](http://www.nea.gov.sg/docs/default-source/our-services/public-cleanliness/covid-19/tripartite-advisory-for-wm-industry-(covid-19)_20200525.pdf)>, accessed 06.07.2020.

Reike, D., Vermeulen, W.J., Witjes, S., 2018. The circular economy: new or refurbished as CE 3.0? –exploring controversies in the conceptualisation of the circular economy through a focus on history and resource value retention options. *Resour. Conserv. Recycl.* 135, 246–264.

Resource Recycling, Inc, 2020. COVID-19 cases disrupt more recycling programs. [resource-recycling.com/recycling/2020/06/30/covid-19-cases-disrupt-more-recycling-programs](https://www.resource-recycling.com/recycling/2020/06/30/covid-19-cases-disrupt-more-recycling-programs). (Accessed 7 June 2020).

Sharma, S., Zhang, M., Gao, J., Zhang, H., Kota, S.H., 2020. Effect of restricted emissions during COVID-19 on air quality in India. *Sci. Total Environ.* 728, 138878.

SMHC, 2020. City Government Press Release. Shanghai Municipal Health Commission (SMHC) wsjkw.sh.gov.cn/xwfb/20200816/8adf67c478444d90905b5b5a54c428cb.html. (Accessed 7 October 2020).

Tan, A., 2019. Singapore aims to send one-third less waste to Semakau Landfill by 2030: Amy Khor. *The Straits Times*. www.straitstimes.com/singapore/environment/spore-aims-to-send-one-third-less-waste-to-semakau-landfill-by-2030-amy-khor. (Accessed 7 August 2020).

World Health Organization, 2020. Advice on the use of masks in the context of COVID-19. Interim Guidance [apps.who.int/iris/rest/bitstreams/1279750/retrieve](https://www.who.int/iris/rest/bitstreams/1279750/retrieve).

WPR, 2020. Shanghai population 2020. *World Population Review (WPR)*. worldpopulationreview.com/world-cities/shanghai-population. (Accessed 7 June 2020).

Yu, W., 2020. “New fashion” has become a “good habit” in the year of household waste segregation in Shanghai. www.shxwcb.com/468869.html. (Accessed 7 June 2020).