The Immediate Italian Response to the Management of Non-medical Waste Potentially Infected by SARS-CoV-2 During the Emergency Phase of the Pandemic

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1 Introduction

After being officially detected in late December 2019 (CDC, 2020) in the city of Wuhan (China) and officially declared a pandemic disease (WHO, 2020a), the severe acute respiratory syndrome (SARS) disease named coronavirus disease 2019 (COVID-19) has infected >75,000,000 peoples across the world causing >1,500,000 deaths (WHO, 2020b).

As reported by de Wit et al. (2016) other two highly pathogenic human coronaviruses were already detected in the last 20 years, the SARS-CoV (in 2002–2003) and the Middle East Respiratory Syndrome (MERS-CoV, in 2012). Other known and diffused human coronaviruses infecting of the upper respiratory tracts belong to the HCoV-229E, HCoV-OC43, HCoV-NL63 and HCoV-HKU1 strains.

When symptomatic, SARS-CoV-2 infection is generally associated with respiratory diseases (i.e. pneumonia, dyspnea, fever) but in some cases also with other symptoms such as headache, diarrhea, vomiting, and nausea (Huang et al., 2020). The most credited transmission pathway for this infection is by respiratory droplets

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generated by infected patients (Lewis, 2020; National Research Council, 2020; Yu et al., 2018; WHO, 2020c). However self-transmission by hands after being in touch with contaminated fomites was also considered another possible transmission route, suggesting interpersonal distance, hand hygiene, and protective mask use as effective preventive measures for limiting the spreading of the infection (Tobias, 2020). Airborne virus transmission (by droplet <5 μm in diameter) at distances greater than 1 m is still a matter of debate (Anderson et al., 2020; Morawska & Cao, 2020, WHO, 2020c). Oppositely, no traces of these studies were reported by Faridi et al. (2020) in air samples captured from 2 m up to 5 m from beds of patients infected by the virus. Nevertheless a systematic review of possible airborne transmission of distances from hospital beds hosting patients infected by SARS-CoV-2 in indoor environment was recently published, suggesting that SARS-CoV-2 may be transmitted through air in poorly ventilated indoor environments (Noorimotlagh et al., 2020). In addition, different experimental studies reported positive results confirming presence and persistence of the virus in indoor air (Santarpia et al., 2020; Liu et al., 2020; Kenarkoohi et al., 2020; Razzini et al., 2020; Chia et al., 2020).

Saawarn and Hait (2021) reviewed the presence of the virus in stools of infected patients suggesting the fecal–oral transmission as a further possible route of transmission (Heller et al., 2020). Twenty-five studies have demonstrated the occurrence of SARS-CoV-2 in human feces, two of which also found live virus isolated in the feces samples (Zhang et al., 2020; Ding and Liang, 2020; Wang et al., 2020). Moreover, SARS-CoV-2 RNA has been identified in raw sewage worldwide (Foladori et al., 2020). Concomitant with the presence of SARS-CoV-2 viral RNA in feces and raw sewage, studies also indicated its occurrence in treated wastewater, primary sludge, and river water (Mohapatra et al., 2020). Although currently there are no studies available to indicate the fecal–oral transmission of SARS-CoV-2 via sewage or wastewater systems (Hindson, 2020; Gu et al., 2020), such transmission cannot be excluded, especially in areas with poor sanitation where contaminated environments can represent a potential medium of virus transmission (Mehraeen et al., 2020).

An ongoing discussion is also associated with the contamination (and decontamination) of inanimate surfaces and the persistence of SARS-CoV-2 on different surfaces and materials represent an important topic (Chin et al., 2020; van Doremalen et al., 2020). Among the available information about the persistence of human and veterinary coronaviruses on inanimate surfaces as well as inactivation strategies with biocidal agents, Kampf et al. (2020) reported that coronavirus can persist up to 9 days and can effectively be inactivated by different biocidal products. It was also noted that other environmental and climatic conditions as temperature, humidity, UV rays concurred to the persistence of the virus on these fomites. In experimental laboratory studies, infectious virus could not be recovered from printing and tissue papers after a 3-h incubation and from treated wood and cloth on day 2. By contrast, SARS-CoV-2 was more stable on glass and banknotes (4 days) and on stainless steel and plastic (7 days). A detectable level of infectious virus was found on the outer layer of a surgical mask on day 7. More recently, other studies (reviewed in Marquès & Domingo, 2020) on the stability and infectivity of SARS-

CoV-2 on inert surfaces have been published (Biryukov et al., 2020; Carraturo et al., 2020; Colaneri et al., 2020; Morris et al., 2020), confirming that SARS-CoV-2 can last on different surfaces for times ranging from some hours to few days. The potential persistence of the SARS-CoV-2 on different surfaces and materials represents a matter of concern for both public health and environment protection also for other areas like schools, cinemas, restaurants, bars, and other places different from healthcare facilities for which specific regulation for infective waste is already implemented (DPR, 2003; WHO, 2020d). In this perspective also household waste represents another potential risk of infection spreading.

In particular, wastes generated in houses with subjects affected by COVID-19 are of particular concern compelling dedicated attention for their management (Nghiem et al., 2020) as well as household wastes from patients in quarantine in private home.

This aspect involves also another important aspect of social life, that is the diffused perception among the general population and the operators about the risk associated with the management of wastes (Gomes Mol & Caldas, 2020). These problems resulted even more emphasized for the workers of the informal sector, a very diffused economic activity in some areas of the world, often operating with no personal protection equipment (PPE) and characterised by the lack of minimal safety and health protection requirements (Cruvinel et al., 2019).

Even if the criteria delivered by the European Commission (EC, 2020) concerning waste management during the COVID-19 crisis recommended not to interrupt the separated collection, the ISS WG considered that it was not possible to neglect the intrinsic complexity of the waste management and the prominent role played by the socio-economic implications.

Indeed, the lack of scientific evidences together with the widespread presence of infected subjects, in some cases not confined in hospitals and medical structures, makes this a very challenging issue (Nghiem et al., 2020).

The Association of Cities and Regions for sustainable resource management (ACR+, 2020) reported that different protocols and practices were implemented by the EU Member States to adopt the waste collection to ensure higher levels of safety and protection to workers.

As an example, higher amount of waste were temporarily stored when its removal was delayed due COVID-19 crisis: incineration of household waste potentially infected by the SARS-CoV-2 and proper procedures for the disposal of PPE used by health care workers treating patients at their home, were introduced in the UK without any modification to plant permission (ACR+, 2020).

In Germany, the National Government indicated to put organic, packaging, and paper waste generated by infected patients treated at home together with residual waste. Other countries (e.g. Spain, Portugal, Estonia) imposed a minimum storage time of 72 h to protect against the risks from waste handling, to allow at least some virus inactivation. Differently, in the USA no specific regulations were introduced for managing household waste suspected to be potentially infected by the SARS-CoV-2, besides the adoption of PPE and other precautions already being imposed by safety regulation for workers. Similar indications were also detected by the Israelian

Ministry of Environmental Protection, by the Ramallah Municipality in Palestine and by the Peruvian Ministry of Environment.

All these different attitudes were also attributable to a lack of knowledge about the virus persistence on surfaces and the role that solid waste and fomites in general can have on the spreading of the COVID-19. The choice of the different approaches were mainly driven by socio-economic and cultural perspective, based on the perception of the potential risk of the transmission of the SARS-CoV-2 infection by the waste management, rather than by scientific well supported evidence.

Based on these considerations, since the 15th March 2020, during the peak of first wave of COVID-19 pandemic, a multidisciplinary working group (WG) was appointed at the Italian National Institute of Health (ISS) gathering medical, biological, environmental, hygiene, and engineering experts also involving different stakeholders such as local authorities and waste management companies. The aim of the WG has been to provide pragmatic response and guidelines for the management of the waste generated by patients that resulted positive to the SARS-CoV-2 tests and/or in compulsory quarantine treated at home or in areas other than hospitals and medical centers (ISS, 2020).

2 Waste Management

The COVID-19 rises the attention on several aspects concerning public and private service, imposing new and challenging actions for their adaptation to the specific emergency situation. Waste management represents, among the other, one of those services on which particular attention was focused by several governments for limiting the spreading of the virus and giving adequate protection levels to both operators and citizens.

Starting from these evidences, the WG was charged to develop proper, feasible, and viable guidelines oriented to protect from the potential infection both the workers of waste collection and treatment and the general population that could be directly and/or indirectly in contact with these potentially infected waste. The guidelines adopted and published in its first version a few days after the start of the hard lockdown, were developed on the basis of the available scientific evidence on the virus persistence on different materials surfaces and on the length of inactivation, also based on the use of disinfectants and/or proper temperatures and length of disposal treatments.

In fact, as known, SARS-CoV-2 virion consists of a spherical particle of $\approx$100 nm diameter, characterized by a positive single stranded RNA genome enclosed by a fragile lipid envelope. The damage of the lipid envelope may inactivate the viral particles making the virus non-infectious even if traces of RNA can be detected also for several hours and/or days.

Based on this evidence the first aspect analyzed by the WG was the identification of the potential infection routes and exposure scenarios through the whole waste management chain, from collection to final treatments and disposal.

The main routes of infections identified were:

1. direct contact with contaminated objects and/or surfaces (Kampf et al., 2020; van Doremalen et al., 2020);
2. contact with airborne droplets at a distance <2 m (Faridi et al., 2020; Liu et al., 2020; Santarpia et al., 2020).

For the waste management, several phases were depicted and analyzed based on the potential involved route of infection and/or exposure to the SARS-CoV-2 (Fig. 1):

1. waste packing and delivering by the users;
2. waste withdrawal by workers and/or trained volunteers;
3. waste transport;
4. waste treatment.

2.1 Waste Packing and Delivering by the Users

Concerning the first step of the whole waste management process, the main related potential routes of infection can be identified as follows: (1) become in contact with surfaces and objects infected by the SARS-CoV-2 during the waste handling; (2) risk of generation of aerosol during withdrawal due to, e.g. waste humidity and bags compression. Due to the potential risk of contamination by the virus of typical objects and different materials of household waste (i.e. plastics, paper, metals, glasses, food, masks, other medical devices) it was suggested as a first general recommendation to interrupt separated collection and to put all the waste commingled in the non-differentiated waste bag. This was proposed also to reduce the risk of virus scattering by the potentially infected materials through several waste streams and facilities with a further potential risk of enhancing the diffusion of the virus. A second important recommendation concerned the proper and adequate packaging of the waste for protecting both the waste handlers and the general population from possible injury and diseases arising from the contact with this waste. Therefore, in order to prevent both waste leakage and their mixing with non-infected waste streams, the use of clearly identified (i.e. by specific color and/or by specific labels) double flexible plastic bags for packing potentially contaminated waste was recommended, together with proper wrapping of sharp materials before its insertion into the double plastic bag. Before their delivery to collection workers or properly trained volunteers, these bags should be adequately sealed by stripes and/or adhesive tape. This last precaution was also indicated by the German government (ACR+, 2020).

In packing infected household waste, citizens should wear single use gloves to be disposed of in a new bag, taking the utmost care to peel downwards, away from the wrist, turning the glove inside out. For preventing the damage of the plastic liner,

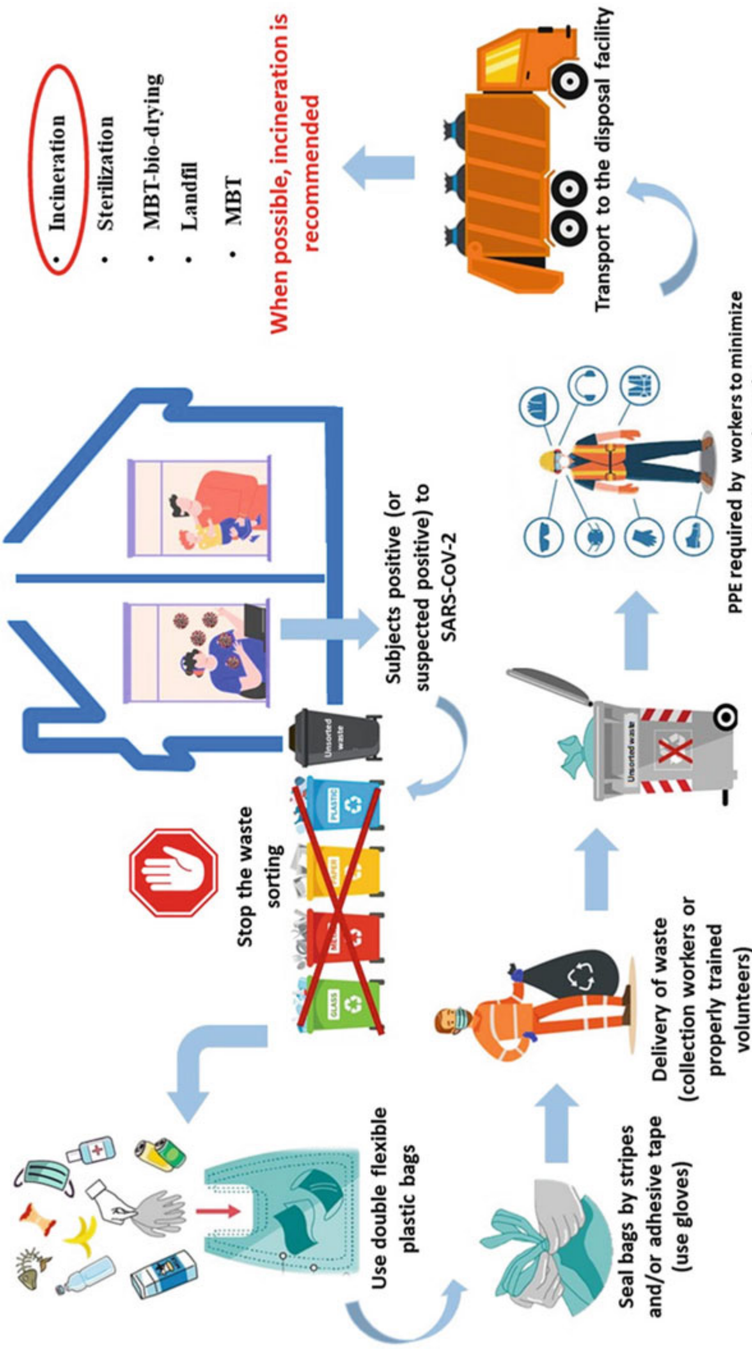

Fig. 1 Main management phases for household waste generated by subjects infected or in quarantine due to the COVID-19

both manual and mechanical compression (e.g. by collection vehicles) have to be avoided.

In addition, the WG also recommended the adoption of specific PPE and "behavior" to prevent contamination/infections of waste operators, as a specific group at risk. It was suggested (1) to wear facial filter masks FFP2 or FFP3 to protect the operator from splashes and sprays; (2) to use a pair of disposable gloves under normal non-disposable work gloves, in order to prevent skin contact with work clothes and masks; (3) a specific order in undressing at the end of the work shift; (4) the way of cleaning work clothes; (5) the replacement of non-disposable work gloves, in case a broken and/or open bag was handled; (6) sanitization of the driver's cab of the vehicles used for the waste collection, avoiding methods that produce splashes or aerosolize infectious material (ISS, 2020).

2.2 Waste Transport

After collection straightforward transport to the disposal facility, avoiding transference stations and other handling operation was also recommended. In this way a further possible contact with these wastes with other materials and with workers is minimized.

Avoiding the use of collection and transport vehicles with automatic compaction systems was also suggested. In fact, larger size vehicles used for the collection are equipped with hydraulic powered compaction systems able to reduce the volume of the loaded waste up to 1:4 (Di Maria & Micale, 2013). This can cause rips in the bags with consequent risk of leakage of waste material representing another potential route for the diffusion of the virus. This risk can also be emphasized if the same vehicle is successively used for other collection routes without preliminary adequate disinfection.

2.3 Waste Treatment

Together with use of disinfectants, temperature and time are identified as the two main parameters impacting the inactivation of the SARS-CoV-2. Chin et al. (2020) reported that temperature >70 °C maintained for not less than 5 min. is able to effectively destroy the infective potential of the virus. Kampf et al. (2020) reported that at lower temperature (up to 4 °C) the virus resulted degraded after >28 days. The same author reported that at temperature ranging from 30 to 40 °C the SARS-CoV survived for a period not longer than 96 h.

Based on this evidence, the most diffused treatment and disposal facilities adopted in the waste sector were ranked on their ability in achieving the inactivation of the virus based on the temperature and on the length of the treatment (Fig. 2).

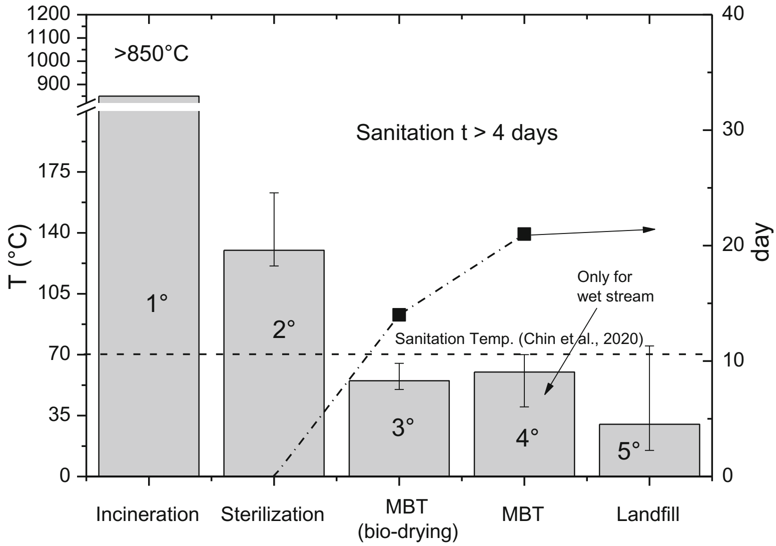

Fig. 2 Ranking of treatment/disposal facilities for household waste potentially infected by SARS-CoV-2 based on temperature and time of the treatment

Due to the high temperature levels (>850 °C) (Di Maria et al., 2018) the incineration was indicated to be the most suitable solution for managing such waste. Direct insertion in the combustion chamber, with priority respect to the other waste stored in the facility was also recommended. For this aim different colors of the bags can facilitate this job. The use of solid PVC bins were not recommended, in particular for lower size facilities (i.e. 100,000 tonnes/year) due to the risk of increase in HCl emission caused by their combustion and by the risk of hopper clogging.

For those areas lacking incineration capacity, sterilization resulted as another suitable treatment due to its ability of maintaining the materials at temperature from 121 °C up to 163 °C (Windfeld & Brooks, 2016) usually by saturated steam (DPR, 2003; WHO, 2020d). By the way, compared to incineration, sterilization shows two main limitations: a) narrowed treatment capacity generally limited to a few tonnes/day and b) necessity of further treatment of the sterilized waste as combustion since its recycling is not allowed by the current Italian legislation.

Another possible alternative can be also represented by the mechanical biological treatment (MBT). The most suitable MBT is the one based on those plants operating according to the bio-drying process, also known as mechanical and biological stability method (Di Maria, 2012; Di Maria et al., 2012). In this case, after shredding and eventually removal of bulky items, the whole waste undergoes to an aerobic treatment, lasting for about 2 weeks and achieving maximum average temperature of about 55 °C. The combination of these two parameters leads to an effective inactivation of the virus. By the way it is strictly recommended to avoid any contact of the waste with the operators until the end of the treatment.

Another largely diffused group of MBT facilities operates according to a different treatment scheme, based on a preliminary size sorting of the inlet waste by the use of trommels and/or disk screens (Di Maria, 2012).

After the sorting operation, the oversize materials (i.e. >100 m average size), consisting mainly of paper and cardboard, plastics, textile, and other high calorific value materials, are generally moved to other recovery and/or disposal treatments/ operations. The undersize, consisting mainly of the organic fraction, is moved to the aerobic biostabilization process lasting on average for 2–3 weeks during which average temperatures >40 °C op to about 70 °C can be achieved. For the MBT of this group of waste, the sanitation requirements are usually verified only for the undersize stream subject to the biostabilization process. For the oversize it is strongly recommended to avoid any contact between the waste stream and the operators, before and after the treatment. Furthermore, storage of the oversize fraction for adequate periods (e.g. >96 h) before any further operation is suggested, since it can provide an adequate level of virus inactivation (van Doremalen et al., 2020; Kampf et al., 2020).

The last option can also be represented by landfilling if particular care is given to the waste handling, storage, and burial. In this case it is recommended the identify clearly the area in which these wastes are disposed, providing also adequate physical separation with other conventional waste streams and daily cover able to avoid any airborne dispersions. For landfilling the only parameter acting for the SARS-CoV-2 inactivation is the time even if temperature >70 °C was also detected in the landfill bodies (Di Maria et al., 2020). By the way it is worthy to highlight that according to the last EU Directive 2018/851/EC the landfilling of infective waste is not more allowed. This means that landfilling of these wastes can be permitted only in the case legal authorities declare the emergency status and just for limited periods.

3 Communication Strategy

Communication together with clarity and soundness is one of the strategic and relevant aspects for a successful implementation and enforcement of regulation and guidelines. The communication to the general population and workers was improved by adding to the guidelines some infographics able to summarize the main recommendations and suggestions by using pictures and bullet point lists written in layman language. Furthermore, the guidelines also respond to the multiple requests of safety procedures coming from stakeholders, including management companies, operators, and citizens during the COVID-19 crisis making the guidelines sound with respect to the current social and economic context.

This said the diffusion of the guidelines was enhanced by adopting different approaches considering also different target audiences (i.e. companies, operators, citizens). Briefly, the communication strategy was based on: (1) dissemination by media and press release; (2) delivering to local authorities; (3) activation of a dedicated section of the web site of the ISS "ISS per COVID-19" (https://www.iss.it/en/coronavirus) for free download; (4) delivery to specific associations.

This was also a keystone activity aimed to increase the awareness of the population on practical measures to contain spreading of the virus and on risk prevention.

4 Conclusion

The COVID-19 pandemic has transformed our way of life and also the production of our urban waste in terms of waste composition and amount. It is now clear that the management of hazardous waste is essential to minimize long-term risks to human and environmental health, but it was a challenge to develop specific and effective guidelines at the beginning of the hard lockdown in Italy for the multidisciplinary working group, involving public administration, waste management companies, universities, and health care competences activated by the Italian National Institute of Health (ISS).

The potential persistence of the SARS-CoV-2 on different surfaces and materials, including waste generated by (a) patients positive to the SARS-CoV-2 and treated at home, (b) subjects in preventive quarantine at home or in dedicated areas different from hospital or medical centers, was perceived as a risk and as a further possible route for virus spreading.

Beside citizens, particular concern was expressed by operators, trained volunteers, other subjects directly involved in waste disposal.

This situation gave rise the request of clear, sound, and adequate information about the proper procedures, practices, and precautions to adopt for avoiding this potential risk.

The group of experts at ISS provided specific guidelines to be adopted by all the subjects directly and indirectly involved in all the different phases of the waste management sector. The integrated approach gathering multidisciplinary expertise along with the involvement of main stakeholders resulted in a winning approach giving a pragmatic but scientifically sounded guidance document in the first emergency period.

The waste handling precaution and adaption varied in different countries, but a timely and dynamic measures are required to cope with this unprecedented situation. In Italy, asking for interrupting the separated waste collection for those patients confined at home or in quarantine was a difficult decision, but this was justified by the need to simplify the disposal procedure for the infected users and to avoid errors that may compromise the health of the waste operators: a risk benefit consideration that although "apparently" not environment-friendly can be considered as a measure to contain virus spreading and preventive for human health in an emergency situation.

References

ACR+. (2020). *Municipal waste management and COVID-19- Phase 1*. Retrieved June 6, 2020, from https://acrplus.org/en/municipal-waste-management-covid-19-phase1#international

Anderson, E. L., Turnham, P., Griffin, J. R., & Clarke, C. C. (2020). Consideration of the aerosol transmission for COVID-19 and public health. *Risk Analysis, 40*(5), 902–907. https://doi.org/10.1111/risa.13500

Biryukov, J., Boydston, J. A., Dunning, R. A., Yeager, J. J., Wood, S., Reese, A. L., Ferris, A., Miller, D., Weaver, W., Zeitouni, N. E., Phillips, A., Freeburger, D., Hooper, I., Ratnesar-Shumate, S., Yolitz, J., Krause, M., Williams, G., Dawson, D. G., Herzog, A., ... Altamura, L. A. (2020). Increasing temperature and relative humidity accelerates inactivation of sars-cov-2 on surfaces. *mSphere, 5*. https://doi.org/10.1128/mSphere.00441-20

Carraturo, F., Del Giudice, C., Morelli, M., et al. (2020). Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces. *Environmental Pollution, 265*(Pt B), 115010. https://doi.org/10.1016/j.envpol.2020.115010

CDC (Centers of Disease Control and Prevention). (2020). *Coronavirus disease 2019 (COVID-2019)*. Retrieved May 3, 2020, from https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/summary.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Fsummary.html

Chia, P. Y., Coleman, K. K., Tan, Y. K., Ong, S. W. X., Gum, M., Lau, S. K., Lim, X. F., Lim, A. S., Sutjipto, S., Lee, P. H., Son, T. T., Young, B. E., Milton, D. K., Gray, G. C., Schuster, S., Barkham, T., De, P. P., Vasoo, S., Chan, M., ... Marimuthu, K. (2020). Singapore 2019 Novel Coronavirus Outbreak Research Team. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. *Nature Communications, 11*(1), 2800. https://doi.org/10.1038/s41467-020-16670-2

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. *The Lancet Microbe*. https://doi.org/10.1016/S2666-5247(20)30003-3

Colaneri, M., Seminari, E., Novati, S., et al. (2020). Severe acute respiratory syndrome coronavirus 2 RNA contamination of inanimate surfaces and virus viability in a health care emergency unit. *Clinical Microbiology and Infection, 26*(8), 1094.e1–1094.e5. https://doi.org/10.1016/j.cmi.2020.05.009

Cruvinel, V. R. N., Marques, C. P., Cardoso, V., Novaes, M. R. C. G., Araújo, W. N., Angulo-Tuesta, A., Escalda, P. M. F., Galato, D., Brito, P., & da Silva, E. N. (2019). Health conditions and occupational risks in a novel group: Waste pickers in the largest open garbage dump in Latin America. *BMC Public Health, 581*, 16–19.

de Wit, E., van Doremalen, N., Falzarano, D., & Munster, V. J. (2016). SARS and MERS: Recent insights into emerging coronaviruses. *Nature Reviews Microbiology, 14*, 523–534.

Di Maria, F. (2012). Upgrading of a mechanical biological treatment (MBT) plant with a solid anaerobic digestion batch: A real case study. *Waste Management & Research, 30*(10), 1089–1094.

Di Maria, F., Bidini, G., Lasagni, M., & Boncompagni, A. (2018). On time measurement of the efficiency of a waste-to-energy plant and evaluation of the associated uncertainty. *Applied Thermal Energy, 129*, 338–344.

Di Maria, F., & Micale, C. (2013). Impact of source segregation intensity of solid waste on fuel consumption and collection costs. *Waste Management, 33*, 2170–2176.

Di Maria, F., Sordi, A., & Micale, C. (2012). Energy production from mechanical biological treatment and composting plants exploiting solid anaerobic digestion batch: An Italian case study. *Energy Conversion and Management, 56*, 112–120.

Di Maria, F., Sisani, F., Contini, S., Ghosh, S. K., & Mersky, R. L. (2020). Is the policy of the European Union in waste management sustainable? An assessment of the Italian context. *Waste Management, 103*, 437–448.

Ding, S., & Liang, T. J. (2020). Is SARS-CoV-2 also an enteric pathogen with potential fecal-oral transmission: A COVID-19 virological and clinical review. *Gastroenterology, 159*(1), 53–61.

DPR. (2003). Decreto del Presidente della Repubblica 15 luglio 2003, n.254. Regolamento recante disciplina della gestione dei rifiuti sanitari a norma dell'articolo 24 della legge 31 luglio 2002, n. 179. (Regulation for the management of medical waste according to art. 24 of the legislation n. 179 of 31st July 2002). *Official Journal of Italian Republic* n. 211.

EC. (2020). *Waste management in the coronavirus crisis*. Retrieved May 3, 2020, from https://ec.europa.eu/info/sites/info/files/waste_management_guidance_dg-env.pdf

Faridi, S., Niazi, S., Sadeghi, K., Naddafi, K., Yavarian, J., Shamsipour, M., Jandaghi, N. Z. S., Sadeghiniiat, K., Nabizadeh, R., Yunesian, M., Momeniha, F., Mokamel, A., Hassanvand, M. S., & Mokhtari Azad, T. (2020). A field indoor air measurement of SARS-CoV-2 in the patient rooms of the largest hospital in Iran. *Science of the Total Environment, 725*, 138401.

Foladori, P., Cutrupi, F., Segata, N., Manara, S., Pinto, F., Malpei, F., Bruni, L., & La Rosa, G. (2020). SARS-CoV-2 from faeces to wastewater treatment: What do we know? A review. *Science of the Total Environment, 743*, 140444. https://doi.org/10.1016/j.scitotenv.2020.140444

Gomes Mol, M. P., & Caldas, S. (2020). Can the human coronavirus epidemic also spread through solid waste? *Waste Management and Research, 38*(5), 485–486.

ISS. (2020). *Gruppo di Lavoro ISS Ambiente e Rifiuti. Indicazioni ad interim per la gestione dei rifiuti urbani in relazione alla trasmissione dell'infezione da SARS-CoV-2*. Versione del 31Maggio 2020. Roma: Istituto Superiore di Sanità; 2020. (Rapporto ISS COVI-19, n.3/2020 Rev. 2). Available at: https://www.iss.it/documents/20126/0/Rapporto+ISS+COVID-19++3_2020+Rev2.pdf/4cbaa7b5-713f-da61-2cac-03e5d3d155b3?t=1591277298239

Gu, J., Han, B., & Wang, J. (2020). COVID-19: Gastrointestinal manifestations and potential fecal-oral transmission. *Gastroenterology, 158*, 1518–1519.

Heller, L., Mota, C. R., & Greco, D. B. (2020). COVID-19 faecal-oral transmission: Are we asking the right questions? *Science of the Total Environment, 729*, 138919.

Hindson, J. (2020). COVID-19: Faecal–oral transmission? *Nature Reviews Gastroenterology & Hepatology, 17*, 259.

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., Zhang, L., Fan, G., Xu, J., Gu, X., Cheng, Z., Yu, T., Xia, J., Wei, Y., Wu, W., Xie, X., Yin, W., Li, H., Liu, M., . . . Cao, B. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet, 395*, 497–506.

Kampf, G., Todt, D., Pfaender, S., & Steinmann, E. (2020). Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *Journal of Hospital Infection, 104*(3), 246–251.

Kenarkoohi, A., Noorimotlagh, Z., Falahi, S., Amarloei, A., Mirzaee, S. A., Pakzad, I., & Bastani, E. (2020). Hospital indoor air quality monitoring for the detection of SARS-CoV-2 (COVID-19) virus. *Science of the Total Environment, 748*, 141324. https://doi.org/10.1016/j.scitotenv.2020.141324

Lewis, D. (2020). Is the coronavirus airborne? Experts can't agree. *Nature, 580*, 175. https://doi.org/10.1038/d41586-020-00974-w

Liu, Y., Ning, Z., Chen, Y., et al. (2020). Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature, 582*, 557–560. https://doi.org/10.1038/s41586-020-2271-3

Marquès, M., & Domingo, J. L. (2020). Contamination of inert surfaces by SARS-CoV-2: Persistence, stability and infectivity. A review. *Environmental Research, 193*, 110559. https://doi.org/10.1016/j.envres.2020.110559

Mehraeen, E., Salehi, M. A., Behnezhad, F., Moghaddam, H. R., & SeyedAlinaghi, S. (2020). Transmission modes of COVID-19: A systematic review. *Infectious Disorders Drug Targets*. https://doi.org/10.2174/1871526520666201116095934

Mohapatra, S., Menon, N. G., Mohapatra, G., Pisharody, L., Pattnaik, A., Menon, N. G., Bhukya, P. L., Srivastava, M., Singh, M., Barman, M. K., Gin, K. Y., & Mukherji, S. (2020). The novel SARS-CoV-2 pandemic: Possible environmental transmission, detection, persistence and fate during wastewater and water treatment. *Science of the Total Environment, 6*, 142746. https://doi.org/10.1016/j.scitotenv.2020.142746

Morawska, L., & Cao, J. (2020). Airborne transmission of SARS-CoV-2: The world should face the reality. *Environment International, 2020*(139), 105730.

Morris, D. H., Yinda, K. C., Gamble, A., Rossine, F. W., Huang, Q., Bushmaker, T., Fischer, R. J., Matson, M. J., van Doremalen, N., Vikesland, P. J., Marr, L. C., Munster, V. J., & Lloyd-Smith, J. O. (2020). The effect of temperature and humidity on the stability of SARS-CoV-2 and other enveloped viruses. *bioRxiv*. https://doi.org/10.1101/2020.10.16.341883

National Research Council. (2020). *Rapid expert consultation on the possibility of bioaerosol spread of SARS-CoV-2 for the COVID-19 pandemic*. National Academies Press. https://doi.org/10.17226/25769

Nghiem, L. D., Morgan, B., Donner, E., & Short, M. D. (2020). The COVID-19 pandemic: Considerations for the waste and wastewater services sector. *Case studies in Chemical and Environmental Engineering, 1*, 100006.

Noorimotlagh, Z., Jaafarzadeh, N., Martínez, S. S., & Mirzaee, S. A. (2020). A systematic review of possible airborne transmission of the COVID-19 virus (SARS-CoV-2) in the indoor air environment. *Environmental Research, 9*, 110612. https://doi.org/10.1016/j.envres.2020.110612

Razzini, K., Castrica, M., Menchetti, L., Maggi, L., Negroni, L., Orfeo, N. V., Pizzoccheri, A., Stocco, M., Muttini, S., & Balzaretti, C. M. (2020). SARS-CoV-2 RNA detection in the air and on surfaces in the COVID-19 ward of a hospital in Milan, Italy. *Science of the Total Environment, 742*, 140540. https://doi.org/10.1016/j.scitotenv.2020.140540

Saawarn, B., & Hait, S. (2021). Occurrence, fate and removal of SARS-CoV-2 in wastewater: Current knowledge and future perspectives. *Journal of Environmental Chemical Engineering, 9*(1), 104870. https://doi.org/10.1016/j.jece.2020.104870

Santarpia, J. L., Rivera, D. N., Herrera, V. L., et al. (2020). Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. *Scientific Reports, 10*, 12732. https://doi.org/10.1038/s41598-020-69286-3

Tobias, A. (2020). Evaluation of the lockdown for the SARS-CoV-2 epidemic in Italy and Spain after one month follow up. *Science of the Total Environment, 725*, 138539.

van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., Tamin, A., Harcourt, J. L., Thornburg, N. J., Gerber, S. I., Lloyd-Smith, M. O., de Wit, E., & Munster, V. J. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *The New England Journal of Medicine, 382*, 12.

Wang, W., Xu, Y., Gao, R., Lu, R., Han, K., Wu, G., & Tan, W. (2020). Detection of SARS-CoV-2 in different types of clinical specimens. *Journal of the American Medical Association, 323*(18), 1843–1844. https://doi.org/10.1001/jama.2020.1585

WHO. (2020a). *COVID-19 2020 Situation summary*. Updated 19 April 2020. Retrieved May 15, 2020, from https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/summary.html#covid19-pandemic

WHO. (2020b). *COVID-19 weekly epidemiologic update*. Retrieved December 10, 2020, from https://www.who.int/publications/m/item/weekly-epidemiological-update-8-december-2020

WHO. (2020c). *Modes of transmission of virus causing COVID-19: Implications for IPC precaution recommendations*. Retrieved May 3, 2020, from https://www.who.int/publications-detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations

WHO. (2020d). *Laboratory biosafety guidance related to coronavirus disease 2019 (COVID-19)*. Retrieved May 3, 2020, from https://apps.who.int/iris/bitstream/handle/10665/331138/WHO-WPE-GIH-2020.1-eng.pdf

Windfeld, E. S., & Brooks, M. S. L. (2016). Medical waste management – A review. *Journal of Environmental Management, 163*, 98–108.

Yu, H., Afshar-Mohajer, N., Theodore, A. D., Lednicky, J. A., Fan, Z. H., & Wu, C. Y. (2018). An efficient virus aerosol sampler enabled by adiabatic expansion. *Journal of Aerosol Science, 117*, 74–84. https://doi.org/10.1016/j.jaerosci.2018.01.001

Zhang, Y., Chen, C., Zhu, S., Shu, C., Wang, D., Song, J., Song, Y., Zhen, W., Feng, Z., Wu, G., Xu, J., & Xu, W. (2020). Isolation of 2019-nCoV from a stool specimen of a laboratory-confirmed case of the coronavirus disease 2019 (COVID-19). *China CDC Weekly, 2*(8), 123–124. https://doi.org/10.46234/ccdcw2020.033