Quantitative and Qualitative Assessment of Healthcare Waste and Resource Potential Assessment

Beate ZLAUGOTNE^{1*}, Jelena PUBULE², Julija GUSCA³, Silvija Nora KALNINS⁴

^{1–4}*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, Latvia*

Abstract – Among other sectors prioritized in delivering the circular economy targets, such a major sector as health care should also be highlighted. According to World Bank data, current health expenditure is still rising, reaching globally 10.02 % in 2016 compared to 8.56 % in 2000. To ensure protection of public health, the management of health care waste should be based on the waste management hierarchy. Besides the preventive measures (waste minimization, green procurement, sustainable planning, environmental management systems), treatment methods should also be viewed in the context of the waste management hierarchy. To analyse the possibility to apply circular economy principles into health care waste management, evaluation of resource recovery alternatives as well as its multi-dimensional assessment was done. In the article quantitative and qualitative assessment was conducted through multicriteria decision analysis with a goal to do a quantitative and qualitative assessment of healthcare waste and resource potential assessment.

Keywords – circular economy; multicriteria decision analysis; resource recovery; valuable health care waste

1. INTRODUCTION

Environmental pollution is causing health problems and even death, in 2015 pollution caused nine million premature deaths which is 16 % from all deaths globally [1]. Healthcare facilities help patients to solve health problems from pollution but at the same time the healthcare sector is one of the major emitters of environmental pollutants [1]. The population is aging and in 2050 people over the age of 60 will double from 901 million to almost 2.1 billion and the healthcare sector needs to deal with new healthcare needs and be more effective at it [2]. Policy-makers in the EU and at the national level have recognized the need to make health systems sustainable by making them more efficient, accessible and resilient [2].

Healthcare waste is divided into non-hazardous and hazardous waste and is strictly controlled with regulations which in case of EU Member states, this includes healthcare waste classification from Annex III of Directive 2008/98/EC and a List of Waste established by Commission Decision 2014/955/EU. According to the World Health Organization, 80–85 % of all healthcare waste is non-hazardous and 15–20 % is hazardous [3]. Healthcare waste is from hospitals, clinics, healthcare centres, dental centres, laboratories, research centres, mortuaries and autopsy centres, animal research and testing facilities, blood banks and collection services and nursing homes [4]. Non-hazardous waste is very similar to household waste which is possible to recycle and more than 50 % of the waste is paper, cardboard and

* Corresponding author.

E-mail address: Beate.Zlaugotne@rtu.lv

plastic and the rest of the waste is food, metal, glass, textiles, and wood [5]. The hazardous healthcare waste consists of sharps (1 %), body parts (1 %), chemicals or pharmaceuticals (3 %) and radioactive and cytotoxic waste (less than 1 %) [6]. Healthcare waste is infectious, pathological, sharp, chemical, pharmaceutical, genotoxic and radioactive waste, and waste must be disinfected before disposal [4]. The World Health Organization has made recommendations to separate healthcare waste in different coloured trash bags and labels. To make waste management effective, it is also important to separate the waste in healthcare facilities into non-hazardous and hazardous waste.

During an outbreak of an infectious disease, the amount of healthcare waste increases rapidly and during the COVID-19 pandemic, the composition of healthcare waste is similar to that which would occur under normal conditions [7]. With the COVID-19 pandemic, the healthcare waste which is hazardous increased and mostly plastic waste from different types of personal protective equipment – face masks, disposable gloves, rubber boots and gowns, hand sanitizers and other medical equipment like syringes, test kits, plastic containers, bandages, tissues and others [8]. Effective waste management during the COVID-19 pandemic is essential as it will reduce the risk of spreading the virus through waste, so effective waste disinfection and management technologies, including recycling options are important [9].

Due to future growth of healthcare waste amounts, there is a need to assess and analyse the current issues in its management in order to properly assess and introduce measures in a timely manner. In the research a literature review was conducted on healthcare waste management, as well as collection of data on healthcare waste compositions in Latvia and management of healthcare waste. After literature and data analysis, alternatives for application of recovered healthcare waste materials as resources were identified. Indicators for the valorisation of healthcare waste were also identified and the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) methodology was used to assess healthcare waste treatment, taking into account the circular economy approach.

2. METHODS

2.1. Literature review

Incomplete management of healthcare waste can be a threat to the environment and the population. Impacts from the disinfection process of this waste can cause environmental pollution, as well as from the incomplete waste incineration process, hazardous substances for human health can be generated in the air and ash. There are several methods by which healthcare waste can be managed or disposed.

The main goal of healthcare waste technologies is to reduce potential hazards from the waste and there are thermal, chemical, irradiative and biological waste treatment technologies and mechanical treatment technologies that are used as the main treatment technologies [10]. Healthcare waste incineration is commonly used as a waste treatment technology, and this technology also affects the environment and population because incineration ash can be toxic which needs to be disposed as hazardous waste [10]. Newer healthcare waste treatment technologies disinfect or sterilize healthcare waste thus leading to the treated waste being cleaner from a biological point of view than ordinary municipal waste and some treatment technologies make it possible to recycle the material or accelerate the natural decomposition of organic waste after treatment [10].

With thermal treatment technologies, pathogens are destroyed with heat and the temperature used depends on if the technology type is a low-heat (100 °C to 180 °C) or high heat (above

850 °C) technology [10]. Autoclaves and continuous steam technologies are low-heat technologies which operate in moist environments and use steam to disinfect the waste [10]. Microwave technologies are moist, low-heat thermal technologies, and frictional heat treatment technologies use moist heat and dry heat thermal processes and waste amounts reduce by 80 % and mass by 25–30 % [10]. Dry heat technologies use dry and hot air to operate and waste reduction can be in the range of 75–80 %, whereas incineration technology is a high heat technology and can reduce waste amount by 80–90 % and mass by 75 % [10].

Through the application of chemical treatment technologies, pathogens are destroyed with chemical disinfectants and the type of chemical disinfectant used depends on the technology's inactivation efficacy, and the waste amount reduction depends on the shredding, grinding or mixing technology used [10]. Popular chemical treatment technologies are chlorine-based chemical technology, glutaraldehyde/quarternary ammonium compound-based technology and lime slurry or calcium oxide technology, alkaline hydrolysis technology and ozone gas technology which has recently been developed [10].

Some irradiative technologies have shown results of destroying pathogens and inactivation efficacy depends on the dose absorbed by the mass of waste [10].

In biological technology enzymes can be used to speed up organic waste destruction which can contain pathogens, but biological technology is mostly used for waste from healthcare facility kitchens [10].

Mechanical technologies are used as an addition technology to shred, grind and mix waste and these technologies improve the efficacy of other applications in terms of heat transfer rate, vapour penetration or contact with chemical disinfectant and reduce waste amount and remove physical hazards, like sharps [10].

2.2. Data analysis

Healthcare waste is collected from different healthcare facilities and in Europe on average amounts to 3.10 kg healthcare waste per hospital bed, in the America it is 4.41 kg/per bed, in Asia it is 2.47 kg/per bed and in Africa it is 0.8 kg/per bed [11]. More waste for one bed is in countries with a high-income and with this diversity in healthcare there is not one best solution for the sector as a whole. Each healthcare facility has a specific type of treatment and this impacts the waste amount and type. According to World Health Organization data, 0.5 kg hazardous waste is produced in hospitals per bed in a day, for a clinic this amount is 0.07 kg hazardous waste per patient in a day and for a basic health unit it is 0.01 kg hazardous waste per patient in a day [12].

According to Eurostat data for 'Chemical and medical wastes' and 'Health care and biological wastes' in the period from the years 2004–2016 on average in Europe 0.15 tons of healthcare waste per capita and 0.09 tons of hazardous healthcare waste per capita were generated (Fig. 1). The most tons of healthcare waste per capita is recorded in Estonia at 1.11 tons healthcare waste and 1.01 tons of hazardous waste. Lithuanian also has a lot of healthcare waste per capita at 0.27 tons, but the country also has one of the lowest hazardous waste per capita at 0.02 tons. Finland with 0.26 tons and Belgium with 0.25 tons of healthcare waste per capita also have low levels of hazardous waste per capita – Finland 0.09 tons and Belgium 0.13 tons.

Fig. 1. Healthcare waste subtotal and hazardous healthcare waste tons per capita on average per 2004–2016 data, Eurostat data [13], [14].

Healthcare waste morphological analysis depends on the season, healthcare facility type and other factors and in this respect, healthcare waste heterogeneous [15]. Healthcare waste from disaster relief consists of plastic (43.2 %), biomass (26.3 %), synthetic fibre (15.3 %), rubber (6.6 %), liquid (6.6 %), inorganic salts (0.3 %) and metals (1.7 %) waste [16]. From children's hospitals healthcare waste consists of plastic (39.3 %), paper (11.15 %), textile (23.8 %), glass and sharps (22.7 %) and other (3.05 %) waste [17]. Common healthcare waste from a clinical pathology laboratory includes infectious waste (69.3 %) – sharps (8.6 %), blood collection tubes (37.4 %), other collectors (17.4 %) and other waste, such as toxic waste (8.6 %), infectious-and-toxic waste (13.7 %) and household types of waste (8.4 %) [18].

Based on literature, the main components of healthcare waste are plastic (39.3 – 50 %), textile (14–31 %), paper (11.2–25 %), glass (0.3–22.7 %), woodware (3.2–20 %), rubber (3.4–6.6 %), metal (0.3–5 %) and other (1.4–18.6 %) waste [15]. The main healthcare waste components are plastic, paper and textile waste and are used in sanitary consumables, like medicine bottles, packaging, bedding and toilet paper [15].

A morphological analysis of healthcare waste was performed to understand what material waste is more common. The composition of healthcare waste depends on the healthcare facility type and Fig. 2 contains data from eight healthcare facilities in Latvia. The data were obtained from the research conducted within the project, which are waste from laboratory, children's hospital, doctors' private practice and different types of hospitals. From all healthcare facilities most of the waste was textile (35 %) and different types of plastic (33 %). The waste also contained different types of mixed materials, like plastic with textile, metal with plastic and within the category 'others' all kinds of small waste fractions are included.

Fig. 2. Healthcare waste by waste material from different healthcare facilities, data were obtained from the research conducted within the project.

The amount of healthcare waste is increasing in Latvia as illustrated in Fig. 3 which shows data from two hazardous waste collection, transportation, management, and processing companies in Latvia. Together both companies in 2015 collected 1684 tons of healthcare waste and in 2019 the amount rose to 2173 tons of healthcare waste, which were classified under the 18 waste code. In five years, the amount of waste has increased by 489 tons.

Fig. 3. Total healthcare waste in Latvia [19].

On average each year, 1668 tons of hazardous waste are collected from waste class 180103 – wastes from natal care, diagnosis, treatment or prevention of disease in humans and waste collection and disposal of which is subject to special requirements in order to prevent infection; 74.5 tons of waste from class 180109 – medicine which is not cytotoxic; 35.3 tons of hazardous waste from waste class 180106 – chemicals consisting of or containing hazardous substances and 29.7 tons of hazardous waste from waste class 180202 – wastes from research, diagnosis, treatment or prevention of disease involving animals and waste collection and disposal of which is subject to special requirements in order to prevent infection.

2.3. Indicator analysis method

For healthcare waste treatment technology comparison seven waste treatment technologies were selected and as thermal technologies those included vacuum autoclaves, autoclaves with integrated shredding, batch wise microwaves, continuous microwave, frictional heat treatment and incineration technologies. The chemical treatment technology selected is sodium hypochlorite-based technology. Some types of healthcare waste need to be treated with higher temperatures because of its hazardous nature, but other healthcare waste, like infectious waste can be disinfected if a certain level of microbiological inactivation efficiency is achieved [3].

Autoclaves were originally used for medical instrument sterilization but in the last few decades healthcare waste treatment is possible with this technology [10]. The process temperature of the autoclave technology is 120–150 °C and operates with a pressure of 2–5 bar [20]. Autoclaves can be used for a wide range of healthcare waste treatment but it is not suggested to use an autoclave for volatile and semi-volatile organic compounds, chemotherapy waste, mercury and other hazardous chemical waste, as well as radiological waste [10]. Low-heat waste treatment technologies, like autoclaves make less air pollution [12].

Vacuum autoclaves take less time to disinfect because they are more efficient at removing air and disinfecting waste [10]. The capacity for a vacuum autoclave is 5 to 3000 kg/hour and the technological advantages are its low impact to the environment and waste residues after treatment are non-hazardous and even possible to recycle [12].

Autoclaves with integrated shredding include a hybrid autoclave which has improved heat transfer into waste, and has a high disinfection level at shorter time [10]. The capacity is 5 to 3000 kg/hour and the technological impact on the environment is low, has no hazardous residues but waste is unrecognizable after treatment and the waste amount is reduced [12].

Microwave technology typically use 2450±50 MHz and 915±25 MHz for disinfection [21]. Using this waste treatment technology it is possible to treat a wide range of healthcare waste, but volatile and semi-volatile organic compounds, chemotherapy waste, mercury and other hazardous chemical waste and radiological waste are not suggested for this waste treatment technology [10]. Microwave technology does not have a significant impact on the environment because wastewater is treated and there are minimal air emissions from this technology [12]. Microwave technology has complex influencing factors of disinfection and for healthcare waste and especially for hazardous healthcare waste this is an important indicator [9].

Batch wise microwave technology advantages are low environmental impact and after treatment waste is not hazardous and the technology capacity is 1 to 210 kg per hour [12].

Continuous microwave technology capacity is 100 to 800 kg per hour and after treatment the healthcare waste is unrecognizable and not hazardous after treatment, the amount of waste is reduced and has low environmental impact [12].

Frictional heat treatment technology heats waste to 150 °C and shreds waste into a powder and for waste disinfection a temperature range of 135 °C up to 151 °C is used [10]. With frictional heat technology it is possible to take care of infectious healthcare waste – glass, plastic, metal, liquids and pathological waste [10]. The capacity is 10 to 600 kg per hour and using frictional heat treatment technology there is low impact to the environment and after treatment the waste is not hazardous and is unrecognizable. Waste reduction is also an advantage of this technology [12].

Sodium hypochlorite based technology is alkaline hydrolysis or alkaline digestion process which in decontaminated aqueous solution turns anatomical parts [10]. This healthcare waste

treatment technology is used for pathological and biological waste treatment, but is not suggested for waste which contain aluminium, tin, zinc, magnesium, copper or galvanized iron as well as concentrated acids, flammable liquids and organ halogen compounds and nitromethane and similar nitro compounds [10]. Advantages of sodium hypochlorite based technology is amount reduction, unrecognizable and not hazardous after treatment and the technology capacity is 600 to 3000 kg per hour [12].

Incineration with a dual chamber technology is known as starved-air incinerators, pyrolytic incinerators, two-stage incinerators or modular combustion units [10]. Incineration technology can treat a wide range of healthcare waste and is specially made for pathological waste, but it is not suggested for pressurized gas containers, large amounts of reactive chemical waste, radiographic wastes (silver, salts and photographic), as well as waste which contains mercury, cadmium or other heavy metals from broken thermometers, used batteries and sealed ampoules or vials that may burst, and radioactive waste [10]. Incineration capacity is 5 to 500 kg per hour and advantages include waste amount reduction and the waste is unrecognizable. Disadvantages of this technology include high impact on the environment due to the possibility of producing hazardous ash, air pollution and risk of burns [12].

To assess technology, indicators must reflect sustainability with environmental, technical and economic aspects [22]. Indicators are delineated as data from the technology and as evaluation from literature analysis.

Environmental aspects include energy consumption (kWh/kg) and water consumption (L/kg) data for each technology, and this represents how much energy and water is used to treat kg of healthcare waste. Other environmental aspects are criteria about water connection, quality, and wastewater, as well as environmental impact criteria and hazardous residues criteria.

In order to evaluate technical aspects, the criteria chosen include technology capacity which is represented by how wide the technology capacity range is and what type of healthcare waste can be treated with the technology because each technology provides information on what kind of waste can be treated. Other criteria include temperature for waste treatment process, the effectiveness of waste disinfection which for hazardous healthcare waste is a very important criterion. For the circular economy aspect, an important technical aspect is the criterion of whether the waste can be recycled after treatment with the technology.

Costs and maintenance criteria for the technology were selected for the economic aspect. In this research the focus is to look at the technical and environmental indicators for waste treatment technologies.

2.4. Multi-criteria decision-making analysis (MCDA)

It is important to use structured and sound arguments in the problem-solving and decision-making process, and thus the multi-criteria decision analysis (MCDA) improves the quality of decision-making [23]. MCDA has a lot of different methods and it is a tool for assessing related and contradictory criteria in order to evaluate alternatives and find the best solution [24].

One of the most popular MCDA methods is TOPSIS and it was presented by Hwang and Yoon in 1981 [25]. TOPSIS is recognized as one of the best MCDA methods that addresses the issue of ranking change that was observed after the application of the method, and one of the advantages of the TOPSIS method is the ability to quickly identify the best alternative [24]. TOPSIS idea is to approach the ideal solution for a problem and is commonly used in engineering to find a solution for multi-objective decision-making problems [26]. The TOPSIS framework starts with collecting input data, than calculations of normalized matrix and weighted standard matrix, the next step is distance from ideal and non-ideal solutions and

calculations of closeness between each alternative to ideal solution and the best alternative is with highest closeness [25].

3. RESULTS AND DISCUSSION

Experts evaluated criteria and gave them weights which are listed in Table 1 and for environmental criteria (C1–C5) weight is 0.4 which was divide to sub-criteria, for technical criteria (C5–C10) weigh is 0.4 which was also divided to sub-criteria and economic criteria (C11) is with 0.2 weight. Table 1 also provides information on each criterion ideal solution – minimal (MIN) or maximal (MAX) and it depends on each criterion qualitative or quantitative data.

TABLE 1. CRITERIA WEIGHTS AND IDEAL SOLUTION

	Criteria	Weight	Ideal value
C1	Energy consumption	0.10	MIN
C2	Water consumption	0.10	MIN
C3	Water connection, quality, and wastewater	0.02	MIN
C4	Environmental impact	0.09	MIN
C5	Hazardous residues	0.09	MIN
C6	Capacity interval	0.08	MIN
C7	Infectivity removal efficiency	0.09	MIN
C8	Temperature	0.08	MIN
C9	Waste recycling after treatment	0.12	MIN
C10	Types of waste can be treated	0.03	MAX
C11	Costs and maintenance	0.20	MIN

The alternatives for technologies included in the evaluation are – vacuum autoclave (A1), autoclave with integrated shredding (A2), batch wise microwave (A3), continuous microwave (A4), frictional heat treatment (A5), sodium hypochlorite-based technology (A6) and incineration (A7).

TABLE 2. NORMALIZED WEIGHTED DECISION MATRIX

	A1	A2	A3	A4	A5	A6	A7
C1	0.0156	0.0039	0.0277	0.0237	0.0866	0.0232	0.0193
C2	0.0890	0.0107	0.0045	0.0000	0.0327	0.0297	0.0000
C3	0.0099	0.0099	0.0099	0.0033	0.0066	0.0066	0.0033
C4	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0569
C5	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0569
C6	0.0149	0.0149	0.0446	0.0297	0.0297	0.0149	0.0446
C7	0.0133	0.0265	0.0531	0.0531	0.0265	0.0265	0.0133
C8	0.0081	0.0000	0.0064	0.0064	0.0096	0.0000	0.0734
C9	0.0291	0.0000	0.0000	0.0582	0.0582	0.0582	0.0582
C10	0.0134	0.0134	0.0089	0.0089	0.0134	0.0045	0.0134
C11	0.0000	0.0894	0.0894	0.0894	0.0894	0.0894	0.0000

In Table 2 the normalized weighted decision matrix is presented and it shows that some alternatives did not have value, but the next step considers the ideal and non-ideal solution for each criterion alternative without values was not defended as ideal or non-ideal solution for criteria.

In Fig. 4 the results from MCDA method TOPSIS place the autoclave with integrated shredding waste treatment technology with a value 0.82 as the technology with the highest evaluation and the second best technology after criterion is chemical treatment technology – sodium hypochlorite based technology with 0.73 value.

Fig. 4. TOPSIS results.

The vacuum autoclave technology was the only technology which after healthcare waste treatment could be possible to recycle waste and this indicator was one of the most important, but in other criteria the technology was not quite good and is not one of the top technologies in this case.

It is possible to recycle healthcare waste in material or energy. From plastic healthcare waste, like IV fluid bags, oxygen tubing and oxygen masks which do not contain body fluids or drugs it is possible to use as material for floor panelling or garden hose and other industrial products manufacturing [27], [28]. It is possible to recycle and use personal protective equipment for the production of different plastic product, like storage containers, outdoor decking, watering cans, outdoor flooring for sports fields and playgrounds [29]. Face masks are recycled and used as plastic and at the moment used as raw material for plastic visor production [30]. Needles and other sharps waste after shredding can be used in concrete as a small part in replacement of sand and compressive strength for cement is better [31]. Glass from healthcare waste can be recycled and used for nano glass production [32], ashes from healthcare waste can be used in cement production [33] and healthcare waste can be used to produce energy using gasification or pyrolysis process [34].

4. CONCLUSION

There are four main categories for healthcare waste treatments– thermal, chemical, irradiative and biological treatment technologies. Each technology has advantages and disadvantages, for example what type of waste can be treated, technology capacity, how

effective is waste disinfection or pathogen destruction, is there some specific requirement for the technology and is there environmental impact resulting from the technology.

In this research, after the selection of criteria for waste treatment in terms of environment, technical and economic aspects and after comparing technologies, the alternative for the best healthcare waste treatment technology is autoclave with integrated shredding technology. The evaluation can be improved and made more accurate in further research by using quantitative data for the comparison of healthcare waste treatment technologies.

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REFERENCES

- [1] Sherman J. D. *et al.* The Green Print: Advancement of Environmental Sustainability in Healthcare. *Resources, Conservation and Recycling* 2020:161:104882 <https://doi.org/10.1016/j.resconrec.2020.104882>
- [2] Pereno A., Eriksson D. A multi-stakeholder perspective on sustainable healthcare: From 2030 onwards. *Futures* 2020:122:102605. <https://doi.org/10.1016/j.futures.2020.102605>.
- [3] Dri M., Canfora P., Antonopoulos I., Gaudillat P. *Best Environmental Management Practice for the Waste Management Sector*. Publications Office of the European Union, Luxembourg, 2018. <http://dx.doi.org/10.2760/50247>
- [4] Emmanuel J. *et al.* Safe management of wastes from health care activities. Geneva, Switzerland: World Health Organisation 2014:79(2):171.
- [5] Health Care Without Harm Europe. Sustainable healthcare waste management in the EU Circular Economy model. 2020:1–7. https://noharm-europe.org/sites/default/files/documents-files/6608/2020-11_HCWH-Europe-position-paper-waste.pdf
- [6] Padmanabhan K. K., Barik D. Health hazards of medical waste and its disposal. In *Energy from Toxic Organic Waste for Heat and Power Generation*. Woodhead Publishing Series in Energy 2019:99–118. <https://doi.org/10.1016/B978-0-08-102528-4.00008-0>
- [7] Das A. K., Islam M. N., Billah M. M., Sarker A. COVID-19 pandemic and healthcare solid waste management strategy – A mini-review. *Science of The Total Environment* 2021:778:146220. <https://doi.org/10.1016/j.scitotenv.2021.146220>
- [8] Haque M. S., Uddin S., Sayem S. M., Mohib K. M. Coronavirus disease 2019 (COVID-19) induced waste scenario: A short overview. *Journal of Environmental Chemical Engineering* 2021:9(1):104660. <https://doi.org/10.1016/j.jece.2020.104660>
- [9] Ilyas S., Srivastava R. R., Kim H. Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Science of The Total Environment* 2020:749:141652. <https://doi.org/10.1016/j.scitotenv.2020.141652>
- [10] Emmanuel J. Compendium of Technologies for the Treatment/Destruction of Healthcare Waste. United Nations Environment Programme, 2012. Available: https://wedocs.unep.org/bitstream/handle/20.500.11822/8628/IETC_Compendium_Technologies_Treatment_Destruction_Healthcare_Waste.pdf?sequence=3&isAllowed=y
- [11] Minoglou M., Komilis D. Describing health care waste generation rates using regression modeling and principal component analysis. *Waste Management* 2018:78:811–818. <http://dx.doi.org/10.1016/j.wasman.2018.06.053>
- [12] World Health Organization. *Overview of technologies for the treatment of infectious and sharp waste from health care facilities*. Geneva, Switzerland: World Health Organization. 2019. Available: <https://apps.who.int/iris/bitstream/handle/10665/328146/9789241516228-eng.pdf?sequence=1&isAllowed=y>
- [13] U. Union European. Generation of waste by waste category , hazardousness and NACE Rev. 2 activity Source of data : Eurostat [env_wasgen] UNIT: Tonne HAZARD: Hazardous and non-hazardous - Total WASTE: Total waste NACE_R2: Households. [Online]. [Accessed 01.05.2021] Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en
- [14] U. Union European. Population on 1 January by age and sex Source of data: Eurostat AGE: Total SEX: Total [Online]. [Accessed: 01.05.2021]. Available: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_pjan&lang=en

- [15] Su G., Ong C. H., Ibrahim S., Fattah M. R. I., Mofijur M., Chong T. C. Valorisation of medical waste through pyrolysis for a cleaner environment: Progress and challenges. *Environmental Pollution* 2021:279:116937. <https://doi.org/10.1016/j.envpol.2021.116934>
- [16] Zhang L., Wu L., Tian F., Wang Z. Retrospection-simulation-Revision: Approach to the analysis of the composition and characteristics of medical waste at a disaster relief site. *PLoS One* 2016;11(7):1–12. <https://doi.org/10.1371/journal.pone.0159261>
- [17] Mohseni-Bandpei A., Majlesi M., Rafiee M., Nojavan S., Nowrouz P., Zolfagharpour H. Polycyclic aromatic hydrocarbons (PAHs) formation during the fast pyrolysis of hazardous health-care waste. *Chemosphere* 2019:227:277–288. <https://doi.org/10.1016/j.chemosphere.2019.04.028>
- [18] Graikos A., Voudrias E., Papazachariou A., Iosifidis N., Kalpakidou M. Composition and production rate of medical waste from a small producer in Greece. *Waste Management* 2010;30(8–9):1683–1689. <https://doi.org/10.1016/j.wasman.2010.01.025>
- [19] Latvian Environmental Geology and Meteorology Center. Environmental Statistics Reports ‘3-Waste.’ [Online]. [Accessed: 01.05.2021]. Available: <http://parissrv.lv/gmc.lv/#viewType=reportIndexView&type=3WA&incrementCounter=1>
- [20] JRC. Best Available Techniques (BAT) Reference Document for Waste Treatment Industries (Draft). 2015.
- [21] Wang J. *et al.* Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. *Environmental Pollution* 2020:262:114665. <https://doi.org/10.1016/j.envpol.2020.114665>
- [22] Deus M. R., Mele D. F., Bezerra S. B., Battistelle A. G. R. A municipal solid waste indicator for environmental impact: Assessment and identification of best management practices. *Journal of Cleaner Production* 2020:242:118433. <https://doi.org/10.1016/j.jclepro.2019.118433>
- [23] Thokala P. *et al.* Multiple criteria decision analysis for health care decision making - An introduction: Report 1 of the ISPOR MCDA Emerging Good Practices Task Force. *Value in Health* 2016;19(1):1–13. <https://doi.org/10.1016/j.jval.2015.12.003>
- [24] Diaby V., Campbell K., Goeree R. Multi-criteria decision analysis (MCDA) in health care: A bibliometric analysis. *Operations Research for Health Care* 2013;2(1–2):20–24. <https://doi.org/10.1016/j.orhc.2013.03.001>
- [25] Yu D., Pan T. Tracing knowledge diffusion of TOPSIS: A historical perspective from citation network. *Expert Systems with Applications* 2021:168:114238. <https://doi.org/10.1016/j.eswa.2020.114238>
- [26] Li X. TOPSIS model with entropy weight for eco geological environmental carrying capacity assessment. *Microprocessors and Microsystems* 2121:82:103805. <https://doi.org/10.1016/j.micpro.2020.103805>
- [27] Vinyl Council of Australia. In Healthcare - PVC Recycling in Hospitals. [Online]. [Accessed: 01.05.2021]. Available: <https://www.vinyl.org.au/pvc-recycling-in-hospitals>
- [28] A guide to recycling PVC medical product waste. [Online]. [Accessed: 01.05.2021]. Available: <https://www.vinyl.org.au/images/vinyl/Sustainability/PVCRecoveryInHospitals.pdf>
- [29] TerraCycle Recycling of Personal Protective Equipment. [Online]. [Accessed: 01.05.2021]. Available: <https://www.terracycle.com/en-US/pages/ppe-recycling>
- [30] FRANCE 24. Face mask recycling: French firm finds way to re-use Covid waste. [Online]. [Accessed: 18.02.2021]. Available: <https://www.france24.com/en/20200827-face-mask-recycling-french-firm-finds-way-to-re-use-covid-waste>
- [31] Hamada K. L., Ismail Z. Z. Sustainable Approach for Recycling Medical Waste Needles to Partially Replace Aggregate in Lightweight Concrete Production. *Advances in Science and Technology Research Journal* 2021;14(1):166–173. <https://doi.org/10.12913/22998624/131557>
- [32] Zhu J., Chen X., Ruan J., Li Y., He E., Xu Z. A safe and efficient technology of recovering nano glass from penicillin bottles of medical wastes. *Journal of Cleaner Production* 2019:229:632–639. <https://doi.org/10.1016/j.jclepro.2019.05.072>
- [33] Kaur H., Siddique R., Rajor A. Influence of incinerated biomedical waste ash on the properties of concrete. *Construction and Building Materials* 2019:226:428–441. <https://doi.org/10.1016/j.conbuildmat.2019.07.239>
- [34] Bujak J. Experimental study of the energy efficiency of an incinerator for medical waste. *Applied Energy* 2009;11:86:2386–2393. <https://doi.org/10.1016/j.apenergy.2009.03.016>