Impact of COVID-19 on healthcare waste generation: Correlations and trends from a tertiary hospital of a developed country

NOTE

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Abstract

The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented an emergency not only from a clinical point of view, but also for the environment due to the largely increased waste disposal. This study aimed at estimating, in the context of current trends, the increase in healthcare waste (HW) generation during the outbreak, based on data from a tertiary hospital. From the purveying office statements of "SS Antonio e Biagio e Cesare Arrigo" Hospital of Alessandria (Italy), monthly HW generation data from January 2015 to March 2021 were retrospectively retrieved. Trends and COVID's impact were evaluated by Interrupted-Time Series design with linear regression models. Locally Weighted Scatterplot Smoothing was used to model the relation between infectious HW generation and proportion of COVID-related bed days. HW

generation rose from 35.9±3.8 tonnes month^{-1} (2.4±0.2 kg per patient-day, kg PD^{-1}) in 2015-2019, to 46.3±6.0 tonnes month^{-1} (3.3±0.7 kg PD^{-1}) during the outbreak. The increasing trend was not appreciably modified as for its slope ($p=0.363$), while a significant level change was found between baseline and outbreak (+0.72 kg PD^{-1}, $p<0.001$). The proportion of COVID-related bed days non-linearly affected the infectious HW generated per patient-day, with steeper increases for proportions above 20%. The study showed a significant rise in HW generation in 2020-2021, reasonably due to the COVID outbreak; in addition, the generally increasing trend was not affected. Therefore, urgent measures are needed to conciliate safety requirements with HW generation issues.

Keywords: Healthcare waste, Waste generation, Infectious waste, COVID-19 outbreak, Hospitalisation days, Trend analyses

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Introduction

The increase in hospital waste generation has represented an emerging issue over the last few decades, both in developing and developed countries, as a product of population (Korkut, 2018) and income growths (Windfeld and Brooks, 2015), and therefore of the increase in health service provision. Moreover, the greater attention paid to the prevention of healthcare-associated infections has encouraged using disposable medical items, with consequently higher waste disposal (Hicks et al., 2021; Tsai, 2021).

The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented a disruptive event: more than 180 million people have been diagnosed with COVID-19 worldwide as of 1st July, and the number of confirmed cases is still increasing

(World Health Organization, 2021). Owing to the virus's infectiousness and the consequent magnitude of the phenomenon, COVID-19 has represented an emergency also from an environmental and operative perspective, since it has enhanced medical waste production due to use of personal protective equipment (PPE) (Liang et al., 2021) such as face masks, disposable gloves and gowns, overboots and single-use head coverings, mainly composed of plastic materials (Henneberry, 2020; Klemeš et al., 2020). The amounts of face masks disposed of during the pandemic, for instance, have been estimated to be at least 42 million per week in the United Kingdom and 214 million per week in the United States (Selvaranjan et al., 2021).

The impact of the pandemic on healthcare waste production has been widely acknowledged as alarming (De Aguiar Hugo and Da Silva Lima, 2021; Sarkodie and Owusu, 2021): beside the broad usage of the already mentioned PPE, the pandemic expanded the need for several items, such as respirators and other life-support devices, individual safety appliances and other disposable plastic-based tools (Rupani et al., 2020), such as gauzes, bandages, plasters, laboratory plates and vials.

As a result, waste production boomed all over the world after the COVID-19 outbreak, especially in the most densely populated areas: for example, China recorded noticeable increases in medical waste from baseline (4902.8 tonnes

day^{-1}) to post-outbreak levels (6606.8 tonnes day^{-1}) (Ma et al., 2020), while waste in the United States is estimated to have increased from 5 million tons (i.e. 4.5 million tonnes) per year to 2.5 million tons (i.e. 2.3 million tonnes) per month (Ilyas et al., 2020) and South Korea saw its daily generated medical waste increasing from less than 10 tonnes before the pandemic to a peak of 50 tonnes in April 2020 (United Nations Economic and Social Commission for Asia and the Pacific, 2020).

Following the classification reported in the Supplementary Material (see §1, *Nomenclature caveats*), in order to provide nomenclature consistency throughout the paper, the term *healthcare waste* (HW) will be used to indicate all monitored hazardous waste (i.e. toxic, chemical, infectious waste), without including municipal-like waste (not included in the hospital's routine surveillance: see Materials and Methods below), while the term *infectious healthcare waste* (IHW) will be used to specifically address waste at high biological and infectious risk (a subset of HW).

Many studies have been conducted to quantify the impact of the pandemic on medical waste production by healthcare facilities (Kalantary et al., 2021; Ma et al., 2020; Wang et al., 2021). However, to our knowledge, no analyses of such impact of COVID-19 have been performed in the context of HW generation trends yet.

115 Hence, this study aimed at estimating the increase in HW production during the
116 COVID-19 outbreak and performing an analysis of the impact of the pandemic in
117 the context of current trends, based on a 6-year data framework from a tertiary-
118 care hospital of a developed country.

119

120 Materials and methods

121 *Data collection*

122 Data on waste generation were retrospectively retrieved from the statements of
123 the purveying office of “SS. Antonio e Biagio e Cesare Arrigo” Hospital of
124 Alessandria (Italy), a hub hospital providing care to a 600,000-inhabitant area:
125 monthly data were collected between January 2015 and March 2021. These
126 statements included the net weight and the respective category of HW (see
127 Supplementary Material, §1, for detailed explanation) generated, on aggregate,
128 by the whole facility, including all hospital wards and departments.

129 This precise routine monitoring of waste generation included HW only, i.e. all
130 waste with a different stream and management compared to regular municipal
131 waste: hence, all that concerned the hospital’s municipal-like waste (e.g. paper,
132 plastic, wood, iron, glass etc., whose disposal happened after no contact with
133 patients) was not included in this analysis due to the absence of reliable data.

Data concerning the total number of hospitalisation days and the number of those related to COVID-19 were extracted by the Accounting and Management Department of the hospital. All these data were collected in an aggregate form only, without any chance of identification of any individual, which ensured conformity of the study with the Italian (Law 2003/196) and European (Regulation EC/2016/679) regulatory framework for data protection and privacy. Thus, a final Microsoft Excel database was built, including all the information required for statistical analyses.

Endpoints

The primary outcomes identified for the analyses were the amounts of HW generated each month by the hospital (taking into account both the total amount and IHW only), considered firstly in absolute form and secondly in relation to patient-days. The relative COVID-related hospital load was quantified through the percentage of hospitalisation days due to positive patients out of the total.

Statistical analysis

Segmented linear regression models were built following the Interrupted Time Series (ITS) method (Bernal et al., 2017), in order to detect trends and level changes in HW generation after the COVID outbreak, by allowing also for the presence of an interaction term to quantify the possible slope change (see

Supplementary Material for detail about statistical design, model building and diagnostics).

Correlation between the amounts of HW generated (in relation to bed-days) and the fraction of bed-days that could be ascribed to COVID-19 was investigated through Pearson's correlation coefficient. Moreover, starting from the available data, the Locally Weighted Scatterplot Smoothing (LOESS) regression (Wilcox, 2017) was used to attempt to estimate the general trend of HW generation in relation to the percentage of bed-days related to COVID-19.

The same analyses were also performed by considering the subset of HW that was classified as IHW, so as to detect possible differences in trends and impact of COVID-19 between various waste categories.

In all cases the significance level was set at $\alpha=0.05$. The statistical software R (version 4.0.5) was used for all computation and plotting (R Core Team, 2020): in particular, the "rms" (Harrell Jr, 2021) and "lmtest" (Zeileis and Hothorn, 2002) packages were used to build the models and to perform relevant diagnostics.

Results

Descriptive statistics

171 Seventy-five monthly observations were available for the analysis, all including
172 data regarding both bed-days and HW generation. Descriptive statistics for the
173 hospital's bed occupancy and waste generation are reported in the
174 Supplementary Material. The proportion of COVID-related bed-days varied
175 according to the epidemic waves, ranging from 3-10% in lower-incidence months
176 (from June to October 2020, and in February-March 2021) to 16-34% in acute
177 phases (in March-April 2020, and from November 2020 to January 2021), when
178 most of the hospital's activity was related to emergency treatments.

179 ***Trend analyses***

180 Considering the whole pre-COVID period (from January 2015 to January 2020),
181 an overall increasing trend was detected for the total generation of HW, with an
182 average increase in the total amount of monthly HW by 1.5 tonnes $year^{-1}$ ($p <$
183 0.0001). The occurrence of the COVID-19 outbreak caused a level change in total
184 HW production, with an increase by 6.1 tonnes $month^{-1}$ compared to the baseline
185 level ($p = 0.0001$), but the slope of the rising trend was not apparently modified
186 by the pandemic (Likelihood Ratio Test, LRT: $p = 0.3628$, Fig. 1). IHW was
187 responsible for the greatest part of the increasing trend (+1.23 tonnes $month^{-1}$
188 per year, $p = 0.0002$), and its level change after the COVID outbreak was even
189 higher compared to that of the total amount of monitored HW (+6.3 tonnes $month^{-1}$
190 , $p < 0.0001$; the trend is shown in Fig. 2a).

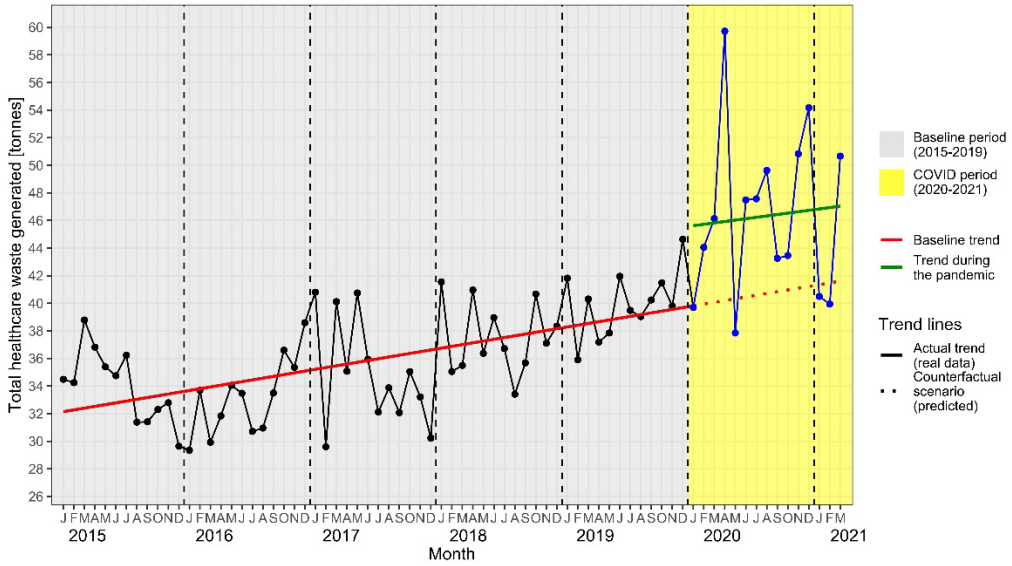
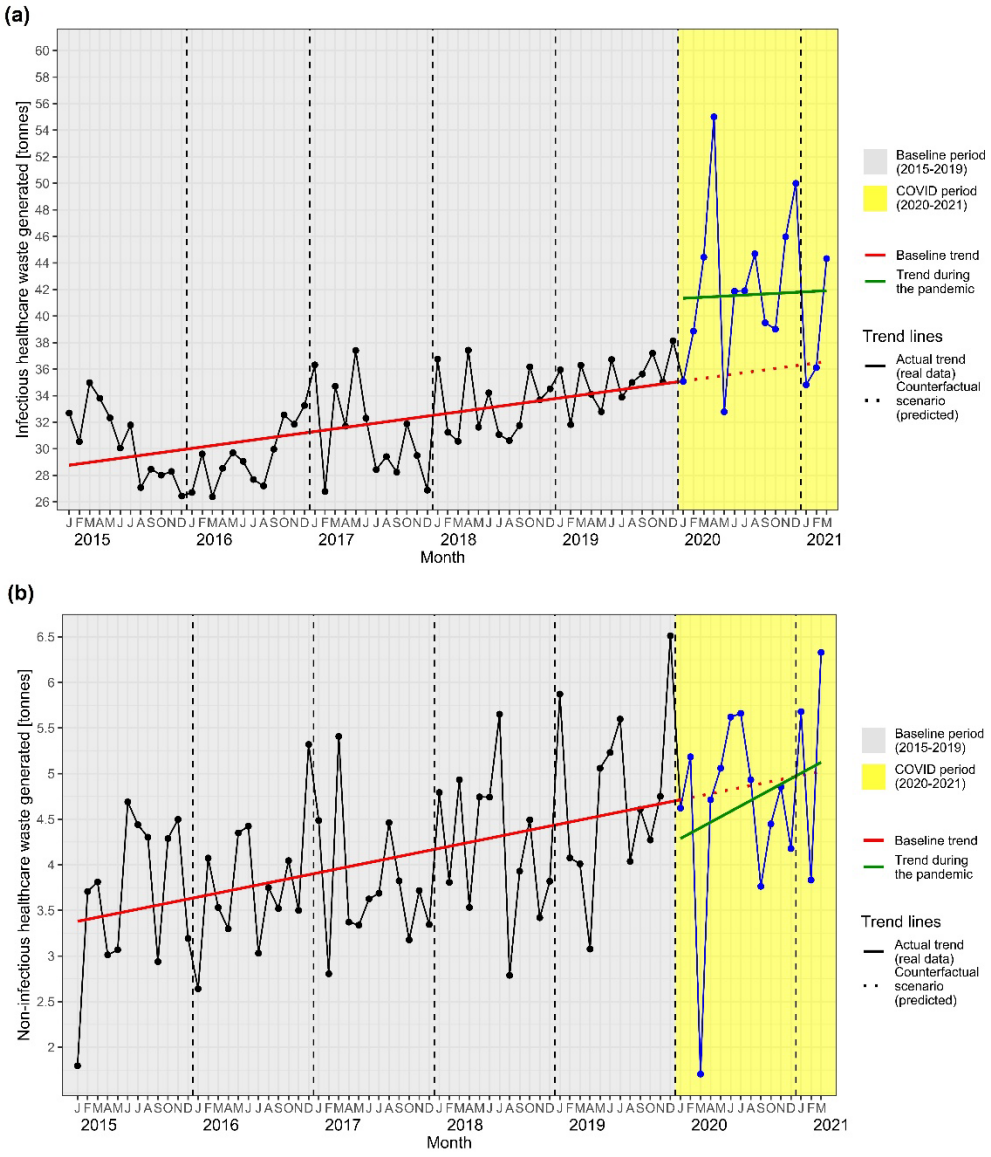


Fig. 1. HW generation trend in "SS. Antonio e Biagio e Cesare Arrigo" Hospital, Alessandria, 2015-2021. All healthcare waste is included, as defined in the Introduction.



196

197 **Fig. 2. IHW and non-infectious HW generation trends in "SS. Antonio**
198 **e Biagio e Cesare Arrigo" Hospital, Alessandria, 2015-2021.** Plot (a)
199 includes infectious waste only, as specified in the Supplementary File, while
200 (b) includes non-infectious (toxic and chemical) waste products.

201

202 This was compensated by a slight decrease (-0.19 tonnes month^{-1}), though not
203 statistically significant ($p = 0.5848$), in the production of other kinds of HW in the
204 COVID period compared to baseline. However, even this waste category showed
205 an increasing trend over time (+274 kg month^{-1} every year) and, after a trough in
206 the most acute phases of the pandemic (March-April 2020), monthly generation
207 rapidly tended to rise back to levels forecast by the pre-COVID trend (Fig. 2b).

208 These absolute figures corresponded to a rise in the total HW produced per
209 patient-day (+0.72 kg PD^{-1} in the pandemic compared to baseline, $p < 0.0001$),
210 of which almost the totality was represented by IHW (+0.7 kg PD^{-1}, $p < 0.0001$).
211 Even in relation to bed days, the rising trend was not significantly affected by the
212 outbreak (LRT: $p = 0.532$) since, both in the pre-COVID and the COVID period,
213 HW generation appeared to grow by around 0.08 kg PD^{-1} per year ($p = 0.0072$).
214 Full detail of the coefficients of all models is reported in Table 1, while trends for
215 HW and IHW generation are depicted in the Supplementary Material (Fig. S1 and
216 S2, respectively).

217

218

Table 1. Model coefficients of ITS regression analyses. For all outcomes (first column), the model without interaction (no slope change) was chosen, according to the criteria specified in the Supplementary Files (see §2): the second column shows the *p*-values yielded by the corresponding LRTs (comparing models with/without interaction). The following columns represent the trend coefficients (β_1 = monthly increase, β_{12} = annual increase) and the estimated COVID-related level change (β_{COVID}), along with respective *p*-values.

Outcome [unit]	LRT *p*-value (interaction)	Trend coefficients and level change [95% CI]	p-value
Total monthly HW [tonnes month^{-1}]	0.3628 (interaction removed)	β_1 = +0.125 [+0.071; +0.179] β_{12} = +1.502 [+0.854; +2.150]	**< 0.0001***
		β_{COVID} = +6.129 [+3.128; +9.129]	**0.0001***
Total HW per patient-day [kg PD^{-1}]	0.532 (interaction removed)	β_1 = +0.006 [+0.002; +0.011] β_{12} = +0.076 [+0.021; +0.131]	**0.0072***
		β_{COVID} = +0.723 [+0.468; +0.978]	**< 0.0001***
Monthly infectious HW [tonnes month^{-1}]	0.2457 (interaction removed)	β_1 = +0.102 [+0.051; +0.154] β_{12} = +1.229 [+0.609; +1.849]	**0.0002***
		β_{COVID} = +6.319 [+3.448; +9.189]	**< 0.0001***
Infectious HW per patient-day [kg PD^{-1}]	0.326 (interaction removed)	β_1 = +0.005 [+0.001; +0.009] β_{12} = +0.061 [+0.008; +0.114]	**0.0254***
		β_{COVID} = +0.700 [+0.452; +0.949]	**< 0.0001***
Monthly non-infectious HW [tonnes month^{-1}]	0.3883 (interaction removed)	β_1 = +0.023 [+0.010; +0.035] β_{12} = +0.274 [+0.124; +0.423]	**0.0005***
		β_{COVID} = –0.190 [–0.881; +0.500]	0.5848

Correlation between COVID-related load and amount of IHW

The amount of IHW generated per patient-day was positively correlated with the proportion of hospital load ascribable to COVID-19 disease (Pearson's $r = 0.687$, $p = 0.0046$). Moreover, with acceptable goodness of fit (Residual Standard Error: RSE = 0.4533), the LOESS smoothing suggested for the non-linearity of this association, with a greater increase of HW generation when the proportion of COVID-related hospitalisation days exceeded 20% (Fig. 3).

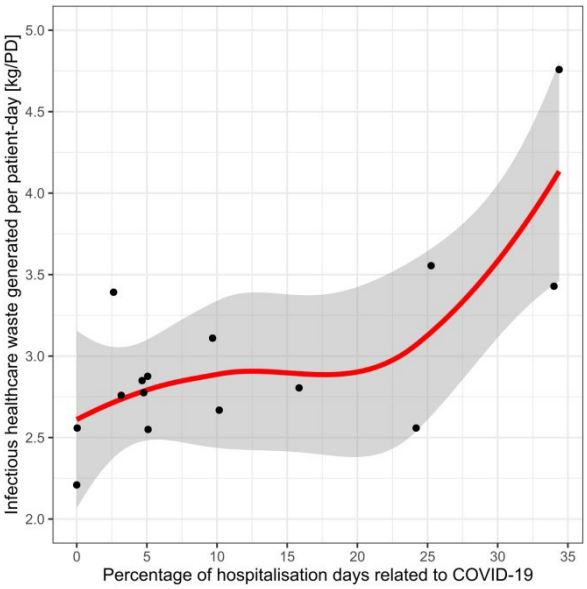


Fig. 3. Correlation between COVID-related hospital load and IHW generation per patient-day. For each month, the relative weight of COVID-19 is expressed as percentage of hospitalisation days ascribable to COVID-positive patients out of the total. The trend identified by the LOESS regression is shown by the red line (and its 95% confidence interval, shaded area).

Discussion

The first result emerging from trend analyses was a general increase in HW production over time. Even in the pre-COVID era, the amounts of HW tended to grow over time (+1.5 tonnes month^{-1} every year, Fig. 1): this was consistent with rising trends found in previous analyses of HW generation, where growths up to +36.6% have been recorded over a 4-year time span (Maamari et al., 2015). Moreover, also considering data in relation to patient-days, the growth estimated by the model (+0.076 kg PD^{-1} every year, Fig. S1) was absolutely comparable to the results obtained before the pandemic, when a 1.25-kg PD^{-1} increase over 17 years (i.e. averagely around +0.074 kg PD^{-1} every year) was demonstrated (Korkut, 2018).

The SARS-CoV-2 outbreak disruptively enhanced this process, first of all because of the systematic introduction of PPE for healthcare workers (Hantoko et al., 2021). In our experience, median hospital waste production rose from 2.4 (pre-COVID) to 3.3 kg PD^{-1} (during COVID), with a relative increase (approximately +38%) that was consistent with data obtained for medical waste both in similar contexts (e.g. France and the Netherlands) (Wei and Manyu, 2021) and in different geographical areas such as China (Ma et al., 2020; Wang et al., 2021). Furthermore, the absolute increase (+0.8 kg PD^{-1}) was aligned with results

reported for medical waste generation in hospital settings: recent studies reported increases up to +3.5 kg PD^{-1} in hospital waste (Kalantary et al., 2021; Zambrano-Monserrate et al., 2020), of which 15-25% is estimated to be represented by IHW (Voudrias and Graikos, 2014; World Health Organization, 2018).

Beside the need to wear PPE for all healthcare and administrative personnel (Nzediegwu and Chang, 2020; Sangkham, 2020), patients' stay itself entailed a higher amount of IHW generated in hospitals: for example, needles and swabs used for routine diagnostics, discarded diapers or disposable cutlery used by COVID-positive patients for everyday meals (Das et al., 2021). Due to the persistence of coronaviruses in the common environment (Kampf et al., 2020), all these kinds of waste were considered as potential vehicles of SARS-CoV-2 transmission (Torkashvand et al., 2021) and therefore treated as hazardous waste according to international guidelines (European Commission, 2020; World Health Organization and United Nations Children's Fund, 2020), even though more recent research has shown that the virus is unlikely to be effectively transmitted through contaminated surfaces or waste (De-La-Torre et al., 2021; Delfino Barboza et al., 2021).

Almost all the increase of HW generated per patient-day (+0.7 out of +0.72 kg PD^{-1}) was represented by biologically hazardous waste. In fact, during the pandemic, the percentage of medical waste that could be ascribed to infectious

282 sanitary waste rose up to 89% in some settings (Kalantary et al., 2021), which
283 was definitely outstanding considering that, before the pandemic, the same
284 proportion did not usually exceed 51-63% in industrialised and developing
285 countries respectively (Aghapour et al., 2013; Diaz et al., 2008).

286 The absolute increase in IHW even exceeded the overall HW increase, while the
287 production of non-infectious waste tended to be reduced during the pandemic.
288 This was linked to the decrease in routine medical services provided by the
289 hospital, similarly to what happened in most hospitals during the re-organisation
290 of their healthcare activities (Panteli, 2020): all diagnostic and therapeutic
291 procedures not strictly related to SARS-CoV-2 management were reduced to a
292 minimum (Amador et al., 2021; Rodríguez-Leor et al., 2020) and, consequently,
293 also the related use of reagents and cytotoxic liquids remarkably dropped.
294 However, after a trough in non-infectious HW production in the very first months
295 of the pandemic, this apparent decrease was rapidly followed by a rebound (Fig.
296 2b), plausibly due to the attempt to restart services previously suspended owing
297 to COVID-19 (Webb et al., 2020). Moreover, infectious and non-infectious HW
298 generation trends might have been also affected by the fact that, in an initial
299 stage, the potential transmission of the virus through waste was still unclear, and
300 thus some items could have been precautionarily classified as hazardous rather
301 than non-hazardous.

The exceptionality of the COVID-related production of IHW is still more evident since IHW generation followed a non-linear pattern according to the relative COVID-related occupancy (Fig. 3). Studies conducted before the pandemic had generally found linear correlations between bed occupancy and daily produced waste at a given time point (Maamari et al., 2015; Sanida et al., 2010): on the contrary, in our experience, higher rates of COVID-positive patients seemed to shove the amount of IHW, particularly when more than 20% of all hospitalisation days were related to COVID. This was probably due to the saturation of the hospital's capacity to provide health care, and to the subsequent adoption of emergency solutions (e.g. patient allocation to other wards and, consequently, further safety measures and disposable items required), which resulted into even higher HW production.

However, the most significant (and worrying) output of this analysis is the apparently unmodified rising trend: this means that the increase in HW is currently being confirmed and COVID-19 has simply shifted HW generation to still higher levels. Such considerations acquire greater relevance as future scenarios are uncertain (Skegg et al., 2021) and the occurrence of variants possibly escaping vaccine-induced immunity (Centers for Disease Control and Prevention, 2021; Kustin et al., 2021) is suggestive of an extension of the COVID period, with potentially unbearable environmental impacts (Wei et al., 2021). In fact, the

322 demand for PPE is estimated to rise at a 6-9% rate up to 2025, even though
323 higher increases are not to be ruled out due to variants' potential impact
324 (International Finance Corporation - World Bank Group, 2020).

325 This study has some limitations. First of all, HW data could be only collected on
326 a monthly basis, with the possibility of a slight time lag (1-5 days) between waste
327 generation, collection and recording; however, these possible fluctuations are
328 likely to be only small and not systematic. Secondly, data were available in an
329 aggregate form only, as this surveillance is not routinely performed at a ward
330 level, which made it impossible to perform between-ward comparisons and
331 correlations that might have offered further research ideas. Eventually, as
332 explained above, our data did not include monitoring of municipal-like waste
333 produced by the hospital, which accounts for an allegedly high proportion of the
334 waste generated by the hospital. Further investigation would be needed by
335 including also this category of waste: nevertheless, our analysis already provides
336 an interesting insight of current trends in HW generation, particularly concerning
337 hazardous medical waste, which is the category of medical waste requiring the
338 most challenging and expensive management (Mol and Caldas, 2020; Windfeld
339 and Brooks, 2015).

340

Conclusions

Waste generation in healthcare settings has represented an increasingly critical issue in the last decades: the COVID-19 pandemic has still enhanced this unenviable rising trends, by requiring additional precautions in clinical care at the expense of a sudden steep increase in HW generation and, consequently, of high environmental costs (Patrício Silva et al., 2020).

This study confirms that, in addition to the already critical burst due to COVID-19, the trend is still heading towards an increase in HW generation, which urges that measures be taken to conciliate patient safety requirements with the need to lower the impact of HW. As the definition and management of infectious waste widely differ between diverse contexts (Mühlich et al., 2003), it would be interesting to perform a similar surveillance in some other facilities both in the same geographical region (Italy) and in different countries, to spot possible differences between various hospitals and to achieve a global perception of hospital waste generation dynamics before and after the outbreak.

Other

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Data Statement

All data collected and analysed for this study, and the relevant computing code, are available upon request to the Corresponding Author of this paper.

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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