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

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1 **NOTE**

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20

21 **Impact of COVID-19 on healthcare waste generation:**  
22 **correlations and trends from a tertiary hospital**  
23 **of a developed country**

24

25

**Abstract**

26 The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented an  
27 emergency not only from a clinical point of view, but also for the environment due  
28 to the largely increased waste disposal. This study aimed at estimating, in the  
29 context of current trends, the increase in healthcare waste (HW) generation  
30 during the outbreak, based on data from a tertiary hospital. From the purveying  
31 office statements of “SS Antonio e Biagio e Cesare Arrigo” Hospital of  
32 Alessandria (Italy), monthly HW generation data from January 2015 to March  
33 2021 were retrospectively retrieved. Trends and COVID’s impact were evaluated  
34 by Interrupted-Time Series design with linear regression models. Locally  
35 Weighted Scatterplot Smoothing was used to model the relation between  
36 infectious HW generation and proportion of COVID-related bed days. HW

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

47

48

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

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60 **Impact of COVID-19 on healthcare waste generation:**  
61 **correlations and trends from a tertiary hospital**  
62 **of a developed country**

63

64 **Introduction**

65 The increase in hospital waste generation has represented an emerging issue  
66 over the last few decades, both in developing and developed countries, as a  
67 product of population (Korkut, 2018) and income growths (Windfeld and Brooks,  
68 2015), and therefore of the increase in health service provision. Moreover, the  
69 greater attention paid to the prevention of healthcare-associated infections has  
70 encouraged using disposable medical items, with consequently higher waste  
71 disposal (Hicks et al., 2021; Tsai, 2021).

72 The SARS-CoV-2 (COVID-19) Coronavirus pandemic has represented a  
73 disruptive event: more than 180 million people have been diagnosed with COVID-  
74 19 worldwide as of 1<sup>st</sup> July, and the number of confirmed cases is still increasing

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

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

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

95 day<sup>-1</sup>) to post-outbreak levels (6606.8 tonnes day<sup>-1</sup>) (Ma et al., 2020), while waste  
96 in the United States is estimated to have increased from 5 million tons (i.e. 4.5  
97 million tonnes) per year to 2.5 million tons (i.e. 2.3 million tonnes) per month (Ilyas  
98 et al., 2020) and South Korea saw its daily generated medical waste increasing  
99 from less than 10 tonnes before the pandemic to a peak of 50 tonnes in April  
100 2020 (United Nations Economic and Social Commission for Asia and the Pacific,  
101 2020).

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

110 Many studies have been conducted to quantify the impact of the pandemic on  
111 medical waste production by healthcare facilities (Kalantary et al., 2021; Ma et  
112 al., 2020; Wang et al., 2021). However, to our knowledge, no analyses of such  
113 impact of COVID-19 have been performed in the context of HW generation trends  
114 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.



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

#### 142 ***Endpoints***

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

#### 148 ***Statistical analysis***

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

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

155 Correlation between the amounts of HW generated (in relation to bed-days) and  
156 the fraction of bed-days that could be ascribed to COVID-19 was investigated  
157 through Pearson's correlation coefficient. Moreover, starting from the available  
158 data, the Locally Weighted Scatterplot Smoothing (LOESS) regression (Wilcox,  
159 2017) was used to attempt to estimate the general trend of HW generation in  
160 relation to the percentage of bed-days related to COVID-19.

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

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

168

## 169 **Results**

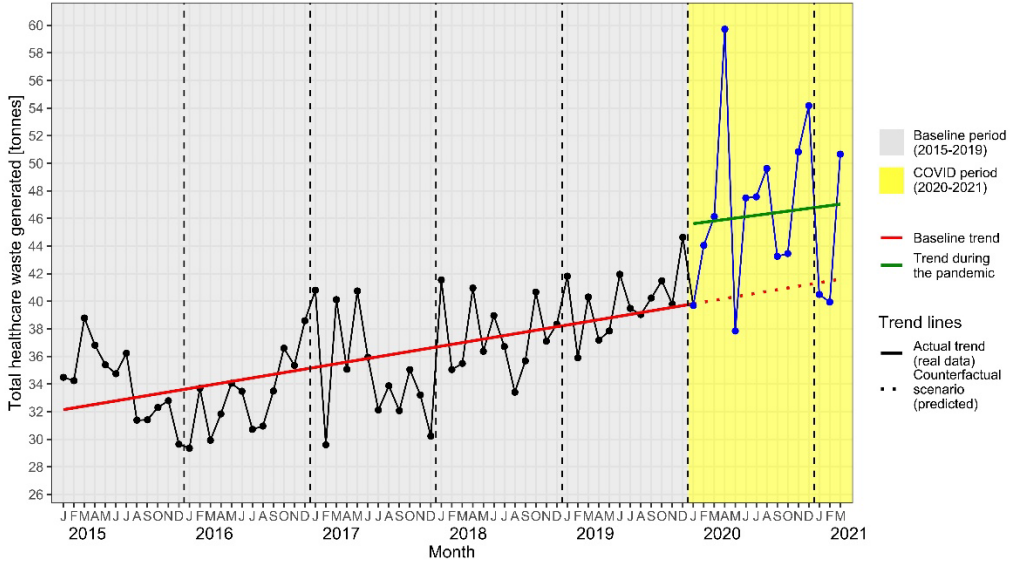
### 170 ***Descriptive statistics***

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<sup>-1</sup> ( $p <$   
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<sup>-1</sup> 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<sup>-1</sup>  
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<sup>-1</sup>  
190 <sup>1</sup>,  $p < 0.0001$ ; the trend is shown in Fig. 2a).

191



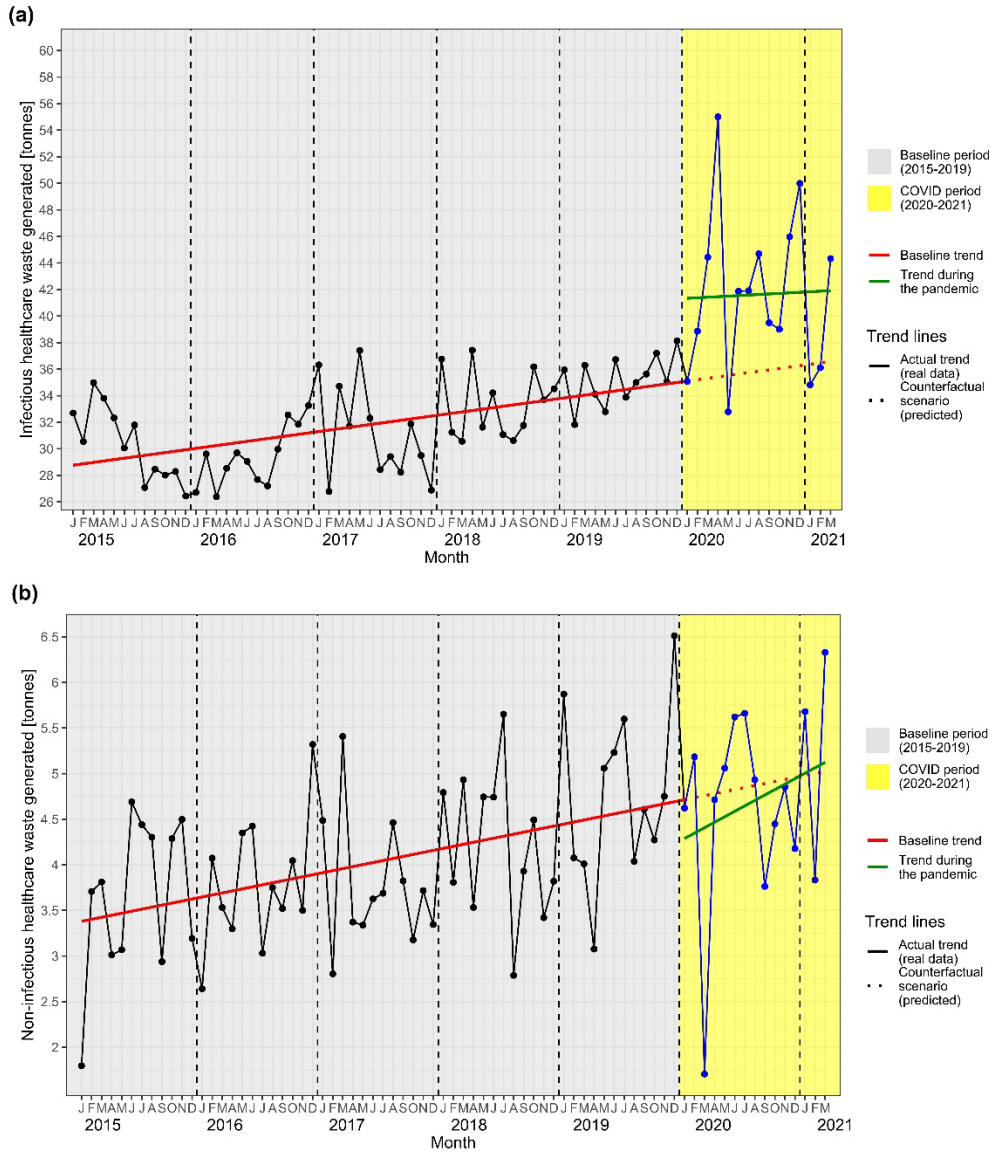
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**Fig. 1. HW generation trend in “SS. Antonio e Biagio e Cesare Arrigo” Hospital, Alessandria, 2015-2021. All healthcare waste is included, as defined in the Introduction.**



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

202 This was compensated by a slight decrease ( $-0.19$  tonnes month<sup>-1</sup>), 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<sup>-1</sup> 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<sup>-1</sup> in the pandemic compared to baseline,  $p < 0.0001$ ),  
210 of which almost the totality was represented by IHW ( $+0.7$  kg PD<sup>-1</sup>,  $p < 0.0001$ ).  
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<sup>-1</sup> 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

219 **Table 1. Model coefficients of ITS regression analyses.** For all outcomes (first  
 220 column), the model without interaction (no slope change) was chosen, according  
 221 to the criteria specified in the Supplementary Files (see §2): the second column  
 222 shows the  $p$ -values yielded by the corresponding LRTs (comparing models  
 223 with/without interaction). The following columns represent the trend coefficients  
 224 ( $\beta_1$  = monthly increase,  $\beta_{12}$  = annual increase) and the estimated COVID-related  
 225 level change ( $\beta_{\text{COVID}}$ ), along with respective  $p$ -values.

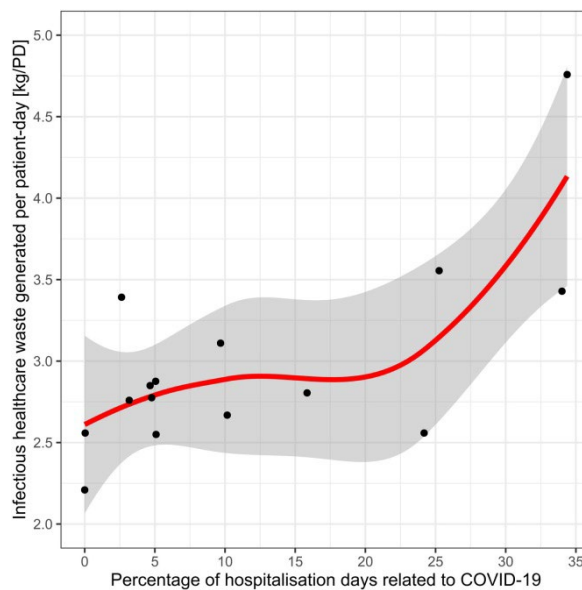
Outcome [unit]	LRT $p$ -value (interaction)	Trend coefficients and level change [95% CI]	$p$ -value
Total monthly HW [tonnes month <sup>-1</sup> ]	0.3628 (interaction removed)	$\beta_1 = +0.125$ [+0.071; +0.179] $\beta_{12} = +1.502$ [+0.854; +2.150]	< <b>0.0001*</b>
		$\beta_{\text{COVID}} = +6.129$ [+3.128; +9.129]	<b>0.0001*</b>
Total HW per patient-day [kg PD <sup>-1</sup> ]	0.532 (interaction removed)	$\beta_1 = +0.006$ [+0.002; +0.011] $\beta_{12} = +0.076$ [+0.021; +0.131]	<b>0.0072*</b>
		$\beta_{\text{COVID}} = +0.723$ [+0.468; +0.978]	< <b>0.0001*</b>
Monthly infectious HW [tonnes month <sup>-1</sup> ]	0.2457 (interaction removed)	$\beta_1 = +0.102$ [+0.051; +0.154] $\beta_{12} = +1.229$ [+0.609; +1.849]	<b>0.0002*</b>
		$\beta_{\text{COVID}} = +6.319$ [+3.448; +9.189]	< <b>0.0001*</b>
Infectious HW per patient-day [kg PD <sup>-1</sup> ]	0.326 (interaction removed)	$\beta_1 = +0.005$ [+0.001; +0.009] $\beta_{12} = +0.061$ [+0.008; +0.114]	<b>0.0254*</b>
		$\beta_{\text{COVID}} = +0.700$ [+0.452; +0.949]	< <b>0.0001*</b>
Monthly non-infectious HW [tonnes month <sup>-1</sup> ]	0.3883 (interaction removed)	$\beta_1 = +0.023$ [+0.010; +0.035] $\beta_{12} = +0.274$ [+0.124; +0.423]	<b>0.0005*</b>
		$\beta_{\text{COVID}} = -0.190$ [-0.881; +0.500]	0.5848

226

227

228 **Correlation between COVID-related load and amount of IHW**

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



235

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

242



## 243 **Discussion**

244 The first result emerging from trend analyses was a general increase in HW  
245 production over time. Even in the pre-COVID era, the amounts of HW tended to  
246 grow over time (+1.5 tonnes month<sup>-1</sup> every year, Fig. 1): this was consistent with  
247 rising trends found in previous analyses of HW generation, where growths up to  
248 +36.6% have been recorded over a 4-year time span (Maamari et al., 2015).  
249 Moreover, also considering data in relation to patient-days, the growth estimated  
250 by the model (+0.076 kg PD<sup>-1</sup> every year, Fig. S1) was absolutely comparable to  
251 the results obtained before the pandemic, when a 1.25-kg PD<sup>-1</sup> increase over 17  
252 years (i.e. averagely around +0.074 kg PD<sup>-1</sup> every year) was demonstrated  
253 (Korkut, 2018).

254 The SARS-CoV-2 outbreak disruptively enhanced this process, first of all  
255 because of the systematic introduction of PPE for healthcare workers (Hantoko  
256 et al., 2021). In our experience, median hospital waste production rose from 2.4  
257 (pre-COVID) to 3.3 kg PD<sup>-1</sup> (during COVID), with a relative increase  
258 (approximately +38%) that was consistent with data obtained for medical waste  
259 both in similar contexts (e.g. France and the Netherlands) (Wei and Manyu, 2021)  
260 and in different geographical areas such as China (Ma et al., 2020; Wang et al.,  
261 2021). Furthermore, the absolute increase (+0.8 kg PD<sup>-1</sup>) was aligned with results

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

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

279 Almost all the increase of HW generated per patient-day (+0.7 out of +0.72 kg  
280 PD<sup>-1</sup>) was represented by biologically hazardous waste. In fact, during the  
281 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.

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

314 However, the most significant (and worrying) output of this analysis is the  
315 apparently unmodified rising trend: this means that the increase in HW is currently  
316 being confirmed and COVID-19 has simply shifted HW generation to still higher  
317 levels. Such considerations acquire greater relevance as future scenarios are  
318 uncertain (Skegg et al., 2021) and the occurrence of variants possibly escaping  
319 vaccine-induced immunity (Centers for Disease Control and Prevention, 2021;  
320 Kustin et al., 2021) is suggestive of an extension of the COVID period, with  
321 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

## 341 **Conclusions**

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

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

356 **Other**

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360 Arrigo” Hospital, Alessandria) for providing aggregate data on hospitalisation  
361 days, both related and not related to COVID-19.

362

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364

365 **Data Statement**

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

368

369 **Declaration of Competing Interest**

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

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