Journal of Material Cycles and Waste Management (2023) 25:3093–3103
https://doi.org/10.1007/s10163-023-01745-1

ORIGINAL ARTICLE

The effect of the Sars-Cov-2 pandemic on the use of personal protective equipment in hospitals

Tijana Ivanović[1] · Carolin Gräbsch[2] · Claudia Som[1] · Bernd Nowack[1]

Received: 31 January 2023 / Accepted: 26 June 2023 / Published online: 6 July 2023

Abstract
The Covid pandemic has strongly affected the use of personal protective equipment (PPE) in the medical sector. Our aim was to assess the influence of Covid on PPE use within a German hospital by analyzing PPE use in four years prior to Covid and in 2020/2021. Numbers of items and mass of different types of PPE were determined based on procurement data. The results show that for the use of gloves the pandemic only had a small effect on the number of items. For body protection there was a clear trend toward a decrease in the number of items used in the years before the pandemic due to actions by the hospital toward a better environmental footprint which was partially reversed by the pandemic. The number of masks on the other hand doubled during the pandemic. Expressed in mass of PPE per patient and day, 15 g of masks, 121 g of gloves, and 183 g of body protection are used, resulting in a total of 319 g of PPE per patient and day. As medical waste has a specific treatment, no direct environmental effects of PPE use in hospitals in a region with well-developed waste treatment system are expected.

Keywords Covid · Personal protective equipment · Healthcare · Material flow analysis

Introduction

Personal protective equipment (PPE) is an umbrella term for items that protect against infection, illness, or injury and includes products such as protective clothing, gloves, masks, face shields/viziers, eyewear, and helmets [1]. As such, PPE is widely used in healthcare. The demand for PPE increased when faced with the rapid onset of Sars-Cov-2 virus in early 2020 (further COVID-19) [2]. In particular, disposable, i.e., single-use PPE was critical in providing protection to healthcare workers and patients in medical facilities and its shortages were noticeable immediately from the pandemic onset [3, 4]. These products act as a temporary barrier for contaminants and infectious agents during the wearing, by which they protect both the practitioner and the patient.

Disposable PPE items refer to those protective products used once and thrown away thereafter. They have a very short life, but require no maintenance for further use. Notable examples include single-use surgical masks, FFP masks, gowns, aprons, gloves, or eyewear. By contrast, the other category of PPE are reusable items that require washing and maintenance but offer long-term use until amortization. Well-known examples include items, like textile overalls and gowns; work pants and jackets; helmets; goggles; and boots.

In the context of a global pandemic, single-use PPE are preferred to durable ones, as they provide the comfort of ready-to-wear, on-demand products. Furthermore, they require no handling past waste separation for management because they are not reused. Single-use PPE is largely made from synthetic materials like polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), and polyurethane (PU) in combination with other materials of diverse origin, like cotton, cellulose, or metal [5, 6]. In the case of gloves, materials of choice include latex and latex substitutes, like nitrile butadiene (“nitrile”) or ethylene vinyl acetate (“co-polymer”). This means that the majority of single-use PPE is made from fossil-based sources (plastic materials), which raises environmental and climate concerns. If managed properly, single-use PPE is a reliable way to protect the health of the wearer and other around them. If littered, such products can cause problems to ecosystems, contribute to microplastic pollution, and could be hazardous to biota if ingested or when resulting in

✉ Bernd Nowack
nowack@empa.ch

[1] Empa, Swiss Federal Laboratories for Materials Science and Technology, Technology and Society Laboratory, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland

[2] BG Klinikum Bergmannstrost, Halle gGmbH, Merseburger Strasse 165, 06112 Halle (Saale), Germany

entanglement [7]. The environmental fate of PPE is therefore tightly related to how regulated and well managed the waste system is—regardless of whether its point of use in a medical institution or a private house.

It is understood that pandemics create higher need for PPE in both the medical sector [4, 7, 8] and in other spheres of life and economy. Our previous research showed that disposable PPE is the most frequent form of single-use plastic products in hospitals even before the pandemic occurred [6]. The "pandemic effect" on PPE consumption in medical sector, i.e., how much more PPE was used during pandemic years relative to regular years, is not well known for the novel COVID-19 infection. The intuitive sense is that the difference between the two periods is notable, but this has not been investigated and the "COVID-19 effect" remains unexplored. For example, the "COVID-19 effect" on mask consumption was a much talked about topic during 2020 and 2021, but the material consumptions and flows have not been researched for the medical institutions. The literature review shows that in the course of the last few years, researchers have considered many health and safety, waste emission, and environmental aspects of the COVID-19 pandemic. Some published articles considered general environmental impacts of health care equipment (Drew et al., 2022), mask efficacy [9]; fiber release from masks and human toxicity [10]; environmental footprint of masks [11]; increased macroplastic pollution due to COVID-19 [8]; repercussions of plastic PPE inflows into marine environments [7]; or evaluation of PPE disposal through life cycle assessment [5].

The data on consumption of PPE at medical institutions therefore remain largely unexplored and worthy of note because medical facilities cannot function without reliable protection of their staff members and patients. Furman et al. (2021) [2] predicted that 90% of all PPE usage is due to surgical masks and gloves. In aiming to determine the "COVID-19 effect" on the use of disposable PPE in healthcare, we performed a material flow analysis (MFA) of such products in a surgical hospital in Germany. We considered four groups of disposable PPE products: masks, body protection, gloves, and medical eyewear. The first two groups feature also the durable version of these products used to compensate for the incurred procurement issues. While the work indeed relies on a case study, projects like this shed light on the PPE (over) use and can be used to understand the patterns of PPE use in future.

Methods

System boundary

This paper considered the consumption of personal protective equipment at the surgical hospital BG Klinikum Bergmannstrost in Halle (Saale), Germany. Firstly, this medical facility is a certified cross-regional trauma center with the approval for severe injury procedures, which belongs to the association of hospitals under the statutory employer's liability insurance. It offers inpatient care related to surgeries, emergency procedures, and physiotherapy as well as outpatient treatments in ambulatory settings, such as minor procedures or diagnostics. We considered the use of PPE in all medical activities taking place in the hospital for a period of 6 years, from 2016 to 2021. The home care or transport, which happen outside of the hospital or the activities of hospital's subsidiaries, remain outside of the system boundary.

The BG Klinikum Bergmannstrost was not part of the first response for COVID-19 patients. Rather, the patients who were admitted to the BG Bergmannstrost came in for other treatments and were simultaneously tested for Covid infection to determine if they would have to be treated with other Covid-positive patients. The hospital predominantly had a role in treating "patients with COVID-19" rather than "for COVID-19." The hospital provided and adapted a separate care unit for such patients. Sometimes, when other higher-priority hospitals had an overflow of patients treated for corona infection, the BG clinic would take them over.

This research distinguishes four product categories of interest within personal protective equipment. "Masks" include surgical masks, special masks (like FFP2, FFP3, KN95), and reusable textile masks, all of which cover the nose and mouth with a varying degree of filtration efficiency and efficacy. "Body protection" (short for body and head protection) include items disposable sterile surgical gowns, protective gowns, foil-based aprons, and washable textile gowns as well as surgical hairnets and headbands that protect the head. "Gloves" include surgical sterile and examination unsterile gloves. Finally, "medical eyewear" includes products such as medical glasses and visor used for eye and face protection, therefore without diopter.

Material flow analysis

The consumption data of all products in personal protective equipment categories were obtained directly from the hospital's data management system for six consecutive years—from 2016 to 2021. The first four years (2016–2019) fall before the COVID-19 pandemic and are, therefore, referred to as "pre-Covid" period. The last two years (2020–2021) fall within the COVID-19 pandemic and are further referred to as "Covid" years. Therefore, the "Covid effect" in this hospital is determined as the change in the consumption rate and trends in the use of PPE between these two periods.

The hospital's data management provided and vetted the annual consumption rates of all products falling into the four mentioned categories of interest. The following data were provided for each product: product name (i.e., article name);

article code (product procurement code); article description (e.g., color, size, composition, packaging size); and the total article annual consumption rate (i.e., annual number of pieces used). Different products with the same functionalities and similar compositions were assigned to the same product group; product groups with similar use cases form a product category (see Table 1). For example, a surgical mask with ear loops qualifies as a "surgical mask," FFP2 masks are "special" masks, but both products belong to the category of "masks."

In order to process the entire dataset, the following steps were taken to calculate consumption rates of each product group. Firstly, consumption rates of all products from the same group were summed together to obtain the group consumption rate. Simultaneously, in each group the most consumed product was located and was from thereon deemed the representative product of its group. Table 1 also shows how important this representative product was (in number of items used) compared to all items of that group. The average value is 70% (range from 16 to 100%), indicating that for most groups the representative product has actually a large share of all products used in that group. All other products within the group were then approximated with this representative product, for which mass was determined later on (see further). The representative fraction of this product in each group in the period of 2016 to 2021 was calculated as the total consumption rate of that product/total consumption rate of the group. These data are available in Table S1 in the Supplementary material, together with the original number of different products per group (Table S2).

Furthermore, the consumption of the group was multiplied with the weight of the representative product to obtain the group mass. The weight of representative products was obtained by weighting one piece of the product on a lab scale, after the article had been obtained from the central storage of the hospital. The articles were measured in the hospital on an ordinary lab scale with ± 0.01 g accuracy. The only exceptions to this approach were the weights of textile and surgical masks which were taken from [11] who had documented them in their comparative life cycle assessment. In addition, products were photographed and their pictures can be found in Figure S1 (Supplementary material). Finally, in order to obtain the annual mass of each category, the results for the corresponding product groups were summed together for each year. Due to very low consumption of medical eyewear, this category was not considered in detail and the consumption data can be found in Table S3.

Finally, the annual mass of each group (category) was expressed per patient day by dividing the total group (category) with the number of patient days for the corresponding year.

Table 1 Product categories, groups, and representative products considered in the analysis

Product category	Product group	Representative article			
		Description	Percentage of total product group[1]	Mass, in g	Source of mass information
Body protection	Sterile surgical gowns	Disposable multi-layer non-woven surgical gowns, 130 cm long	86.1%	197	Measured
	Protective gowns	Disposable synthetic gown, polypropylene non-woven fabric, 35 g/m^2	93.7%	84.4	Measured
	Foil aprons	Disposable aprons from polyethylene foil, 120 cm long	100%	13.2	Measured
	Textile gowns (washable)	Durable, washable medical gown from cotton	100%	336	Measured
	Hairnets & caps	Generic bouffant cap with elastic	38.2%	3.6	Measured
Masks	Surgical masks	Disposable, standard surgical mask, 3 layers, with ear loops	49.8%[2]	2.9	[11]
	Special masks	Disposable, standard FFP2 mask	81.1%	5.5	Measured
	Textile masks (washable)	Durable textile mask with ear loops	100%[2]	11.8	[11]
Gloves	Surgical gloves	Disposable, non-powdered pack of sterile latex gloves, size 7	16.2%	10.4	Measured
	Examination gloves	Disposable non-powdered nitrile, size M	43.2%	3.6	Measured

[1]In % of the total annual group consumption

[2]Representative product is taken from the literature, not extracted from the hospital storage for measuring

Results

The hospital before and during the COVID-19 pandemic

The inpatient capacity, i.e., the number of available beds, varied from year to year and spans from 565 beds (2016–2017) to 571 beds (2018–2021). The average occupancy rates of the beds span from 77.1% to 85.6% of the installed bed capacity. Furthermore, the number of admitted inpatients, the average inpatient stay, as well as the annual number of procedures and outpatients vary as demonstrated in Table 2. Because of these fluctuations, we report the results in addition to total numbers also relative to patient numbers.

While many indicators of the hospital vary as depicted in Table 2, it is important to note that outpatient to inpatient and surgery to inpatient ratios remain largely stable pre- and during Covid. For every inpatient treated at the hospital, 3.4–3.8 outpatients come for diagnostics, check-ups, or smaller treatments at the ambulatory care. Similarly, from the ratio of surgeries to inpatient numbers, one can summarize that 64–69% of all inpatients go through the surgery, while the remaining of inpatients do not require them or are admitted from extended functional and physiotherapy.

As data in Table 2 show, the COVID-19 pandemic had adverse effects on the bed occupancy rate which fell due to two primary factors. Beds were intentionally kept free and unoccupied due to the Government mandate. In addition, a number of workers fell ill in private and the decreased capacity of the hospital to treat patient resulted in a reduction of bed occupancy from average 84.3% pre-Covid to the average 77.7% during Covid.

Finally, an important aspect of the pandemic management were the decisions taken to slow down and counter the spread of the infection. During the pandemic, the mandates were an important part of the response since they can influence the PPE consumption and interpretation of results in this paper. The regulatory response includes decisions of the Government as well as hospital's Pandemic Response Team (PRT) both of which led to increases in safety measures such as PPE mandates for staff, visitors, and patients or distribution of PPE at work or for private use. The timeline of regulatory changes, therefore, has an important role to play in the result interpretation. The pandemic erupted in January 2020 with the first official case in the state of Bavaria on January 27, 2020. The Covid effect in 2020 is therefore only noticeable for 11 months. Germany imposed a lockdown and visitors in the hospital were not allowed from mid-march 2020 until 29th of May. Between 29th of May and 30th of October was a restricted visitor permit. After 30th of October 2020 visitors in the hospital were not allowed again.

On November 20, 2020, the PRT suggested that FFP2 and/or KN95 masks be worn for those whose contact with patients surpasses 10 min. On December 10, 2020, the PRT suggested all staff members to wear a FFP2/NK95 mask in

Table 2 Hospital statistics pre- and during COVID-19 pandemic

	2016	2017	2018	2019	2020	2021
Number of available beds	565	565	571	571	571	571
of which beds in Intensive care + burns	21 + 8	21 + 8	21 + 8	21 + 8	29 + 8	29 + 8
of which beds in Intermediary care (post-anesthesia)	8	8	8	16	10	10
of which beds in Stationary care	528	528	534	526	524	524
Average bed occupancy rate	83.7%	85.6%	83.6%	84.4%	78.4%	77.1%
Average bed occupancy pre-Covid	84.3%				–	
Average bed occupancy during Covid	–				77.7%	
Total number of admitted inpatients	14 410	14 958	14 301	14 586	13 270	12 731
of which Covid-confirmed inpatients	0	0	0	0	140 (1.1%)	525 (4.1%)
Average inpatient stay, in days	12.0	11.8	12.2	12.1	12.3	12.6
Total number of outpatients	54 250	53 394	52 501	50 224	44 473	N/A
Total number of surgeries and ER procedures	9 896	10 025	9 370	9 364	8 779	8 519
Outpatient to inpatient ratio[1]	3.8	3.6	3.7	3.4	3.4	N/A
Surgery to inpatient ratio[2]	0.69	0.67	0.66	0.64	0.66	0.67
Total inpatient days[3]	172 693	176 426	174 298	175 861	163 397	160 584

[1]Total number of outpatients/total number of admitted inpatients

[2]Total number of surgeries and ER procedures/total number of admitted inpatients

[3]Total number of available beds × bed occupancy rate × 365

the hospital regardless of the patient–practitioner contact time. On December 23, 2020, the PRT made the wearing of the masks obligatory for all staff members (about 1600 people) regardless of their job description. In January and February 2021, the hospital proceeded to distribute 20 pieces of FFP2 masks to all staff members. From then on, visitors were required to wear FFP2 masks and were given new FFP2 masks at the entrance. All these masks are also included in the PPE numbers reported below.

Number of PPE items

As expected we can observe an increase in the consumption of masks from pre-Covid to Covid years (Fig. 1a). The use of masks doubled in the Covid years. The prevalence of special masks grew rapidly from minimal use in pre-Covid use to dominance in 2021. In fact, in 2021, the increase of the special masks is noticeable because of the regulatory response in mandating the use of FFP2 masks in lieu of standard surgical masks. Moreover, the use of textile masks is related to the start of the pandemic (spring 2020) when the hospital distributed 2–3 masks to each employee for private and professional use. The intention of such a decision was to preserve surgical masks for surgery and intensive care. As studies on the effectiveness of different masks came out, textile masks were not admitted anymore within the hospital. However, employees were advised to wear textile masks in the private environment, as mouth–nose protection and FFP2 masks were not available in stores at that time. The relevance of textiles masks is therefore limited.

Gloves were the most dominant PPE items across time and categories with about 4.5 million pieces annually (Fig. 1b). As such, gloves did not experience a consumption boom. The relative increase from the pre-Covid to the Covid era is rather small, amounting to about 10%. This is because gloves are used generally in all interactions of practitioners and patient and will therefore be explored in detail with patient day metrics. This is most noticeable for surgical gloves since they are used in surgeries only.

The number of items of body protection is shown in Fig. 1c. One can notice a decreasing trend in the use of body protection in pre-Covid years driven primarily by the reduction in the use of protective gowns (non-woven, non-sterile). There are two principle reasons for this: (1) The rationalization effort by the hospital management to minimize the use of body protection wherever technically feasible and (2) Incurred procurement issues for protective gowns already in 2019. These two reasons led to reinstating of about 1800 washable gowns in 2019. With the procurement bottleneck in 2020 and 2021, the problems were only exacerbated and the use of washable alternatives boomed to 10 times the pre-Covid levels. The protective gowns and surgical gowns were kept strategically for surgical rooms and those treating Covid patients. In addition, foil aprons made of thin foil were used wherever possible. Moreover, as the name suggests, surgical gowns are related to the use in surgery; hence, their use is related to the capacity of the surgical wing and its use. The use of caps remains largely untacked between the pre-Covid and Covid years. Caps are also predominantly used in surgery, hence depend on surgical procedures.

Mass of PPE items

After combining the weights of the representative products with the group's consumption, the mass of the different PPE items was obtained (Fig. 2). Some differences compared to Fig. 1 can be seen because of the different weights of some products within a group. For example, special masks are heavier than the surgical ones, so they also take over in mass as of 2020. Gloves follow the same behavior as in numerical quantity. In the body protection group, the products have very different weights from 3.6 to 336 g, so the contribution to the overall weight in this group is different from the number of items. Hairnets and foil apron become less important, while the washable gowns contribute a larger share to the overall mass.

Comparing the total consumption of PPE product categories

In Fig. 3, the agglomerated values from the three groups are added up to visualize the contribution of each group to the overall number of items and mass. Gloves are by far the most used PPE in terms of number of items, followed by body protection and finally masks (Fig. 3a). The trend in the mass (Fig. 3b) does not follow the number of items since the weight of the products has a major role to play. While the consumption (quantity) of PPE is driven by gloves, they only account for about a third of the mass. The opposite is true of body protection. It is substantially heavier as Table 1 shows, but used in thousands, not millions. Masks have a small contribution, despite having the biggest relative increase from pre-Covid to during Covid.

Covid effect on each product category

By taking into account the mass of all PPE in a group and dividing the values with the patient days, we obtain the average use of PPE group per inpatient. This analysis is necessary as the number of inpatients varies from year to year and is smaller during the pandemic. For masks the expected increase per inpatient is confirmed (Fig. 4a). The Covid effect results in the increase from an average 4.6 g pre-Covid to 14.6 g during Covid, which is a 217% increase compared to pre-Covid. For gloves, the Covid effect amounts to an increase from an average of 109 g pre-Covid to 121 g

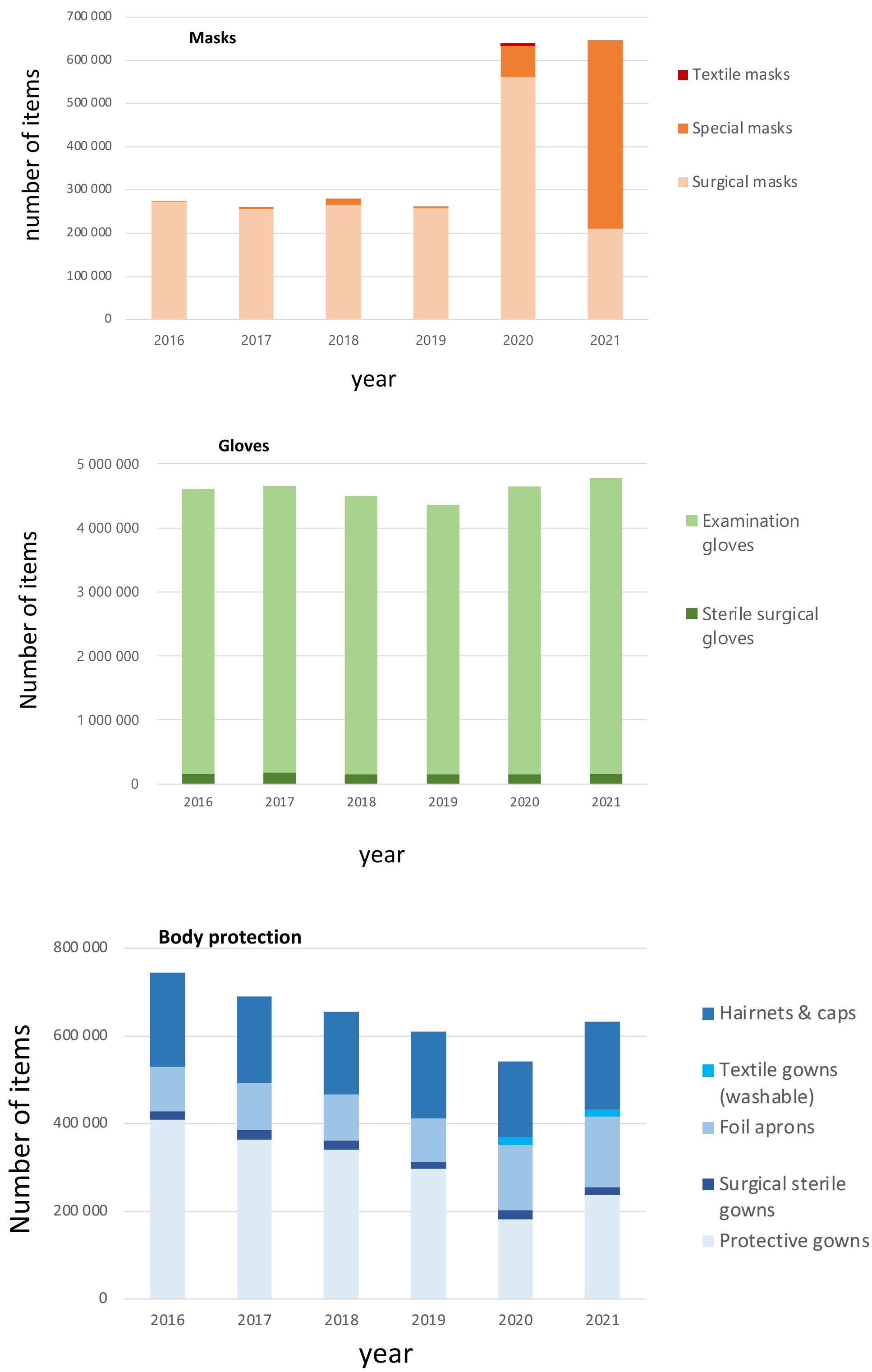

Fig. 1 Annual consumption (number of pieces) of PPE products groups per product category from 2016 to 2021: **a** masks, **b** gloves, and **c** body protection

during Covid, that is, an 11% increase compared to pre-Covid (Fig. 4b).

From 2016 to 2019 there is a linear decreasing trend of body protection consumption per inpatient (Fig. 4c). The reasons and compensation effects are the same as presented in Fig. 2 and are due to functional exchange of protective gowns for foil aprons and procurement issues already in 2019. The decreasing trend during pre-Covid trend in the reduction of PPE is disrupted by the pandemic. Based on

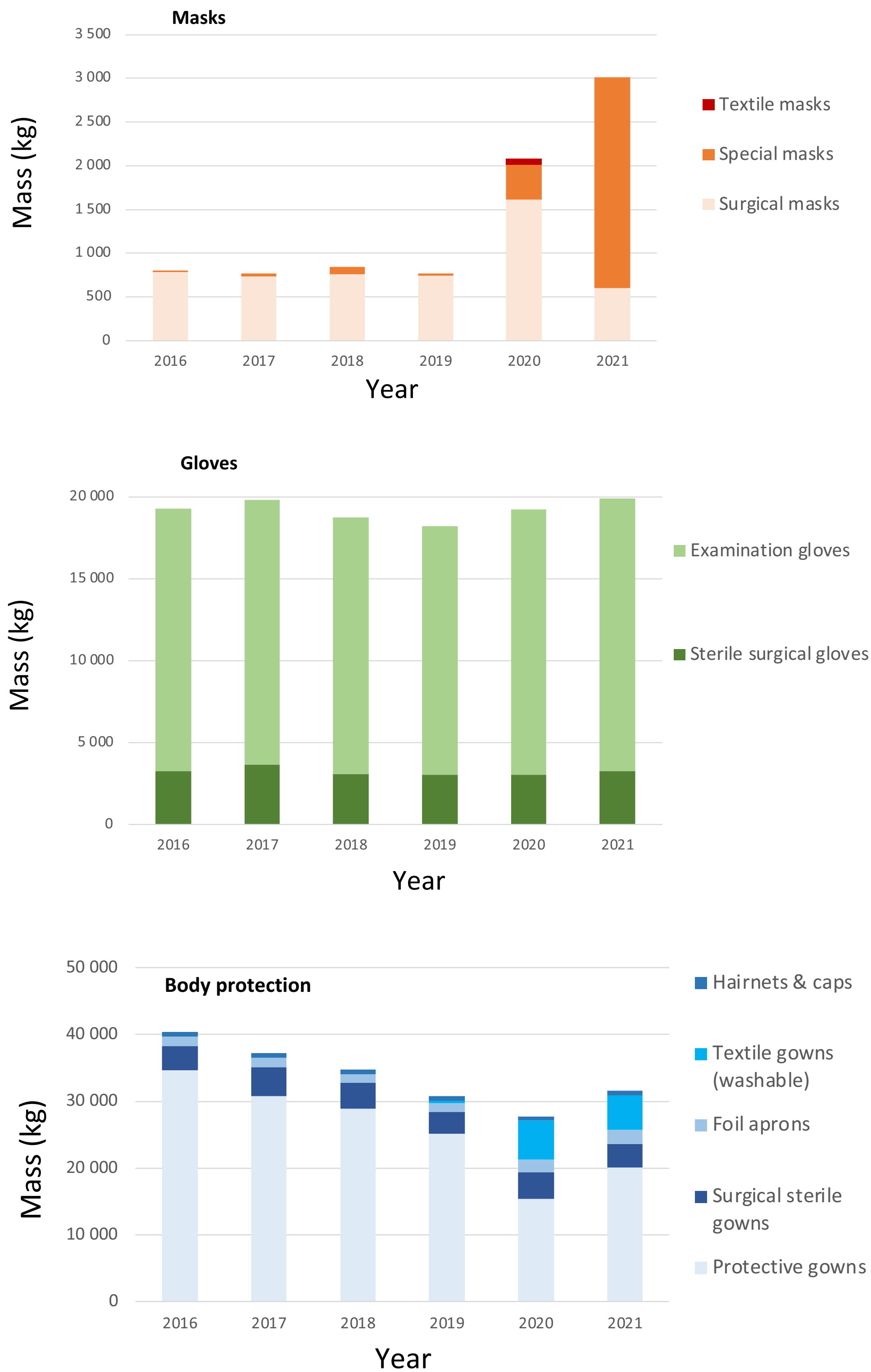

Fig. 2 Annual mass (in kg) of PPE product categories from 2016 to 2021: **a** masks, **b** gloves, and **c** body protection

a continuation of the trend from 2016 to 2019 (under the assumption that further improvements are possible), the expected value for 2020 would have been 150 g without the pandemic. The Covid average is 183 g, therefore the Covid effect amounts a 22% increase from the pre-Covid trend.

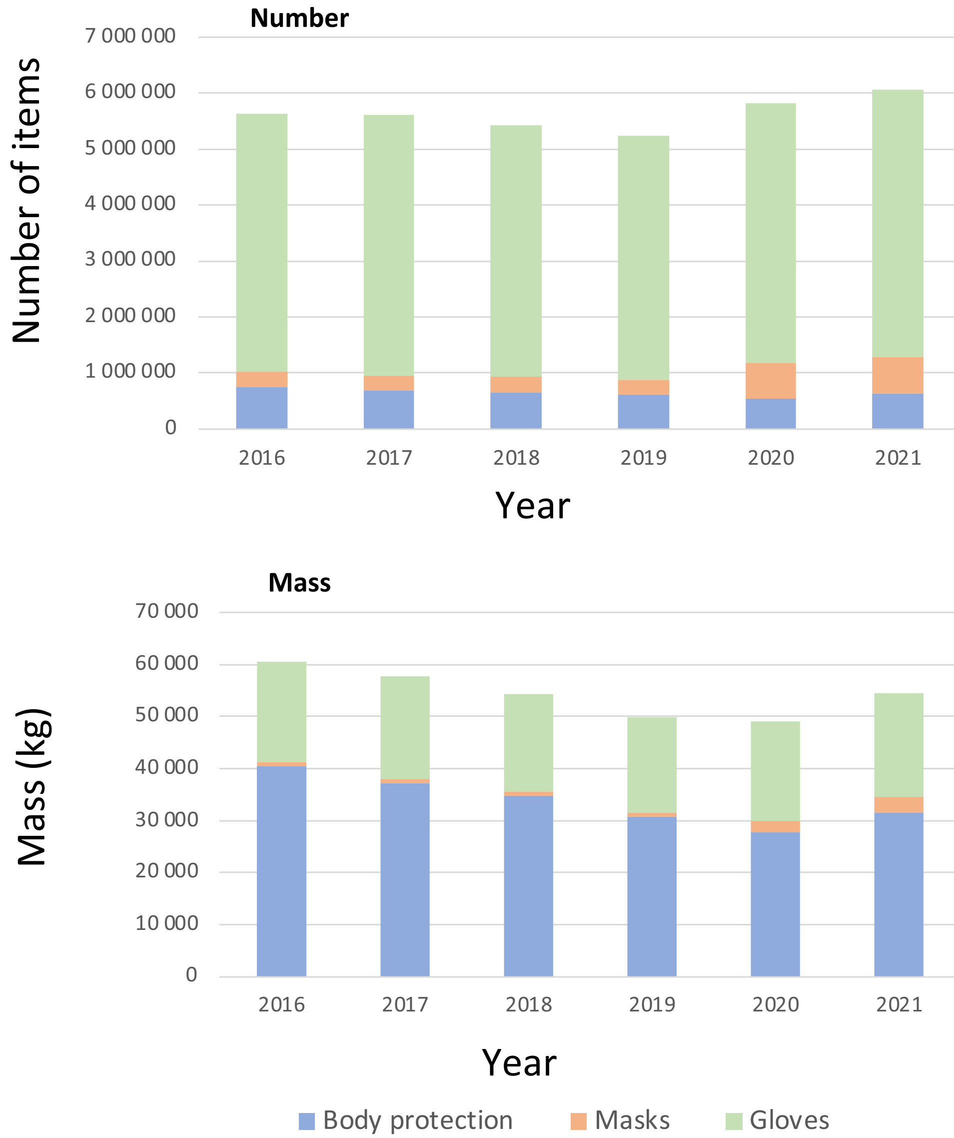

Fig. 3 Total consumption of PPE and single-use PPE, in number of items (**a**) and in mass (**b**)

Discussion

The general population experienced during the Covid pandemic a sudden surge in the use of PPE and a visible «explosion» of their littering in the environment, especially of masks. This has resulted in intense discussions on their effects on the environment and questions on their sustainability. The current work explored how PPE use in hospital was affected by the pandemic. Different to the general population, PPE use in hospitals was already on a high level. Using a very detailed dataset from a hospital for the years before Covid and during Covid, we were able to get detailed insights.

The general assumption was that also in hospitals Covid resulted in a large increase in PPE. However, the results from our work show that different drivers determine the overall effect. A first remarkable trend was a sustained decrease in the use of body protection in the years before Covid. This was caused by efforts of the hospital to reduce the use of single-use materials in the context of improving its environmental footprint. This trend was then stopped by the pandemic. From all PPE categories only the number of masks increased considerably as during the pandemic masks were not only used during surgical procedures or direct patient contact but throughout the whole hospital.

Gloves have a substantial impact on the total PPE consumption in terms of number of pieces. Furman et al. (2021) [2] had predicted that 90% of all PPE usage during pandemic is due to surgical masks and gloves. We observed something similar. In fact, consumption of gloves is led by patient–practitioner interactions [2] and as such is part of the everyday care, examinations, and procedures so the increase in number from pre- to during Covid is not spectacularly high as for masks.

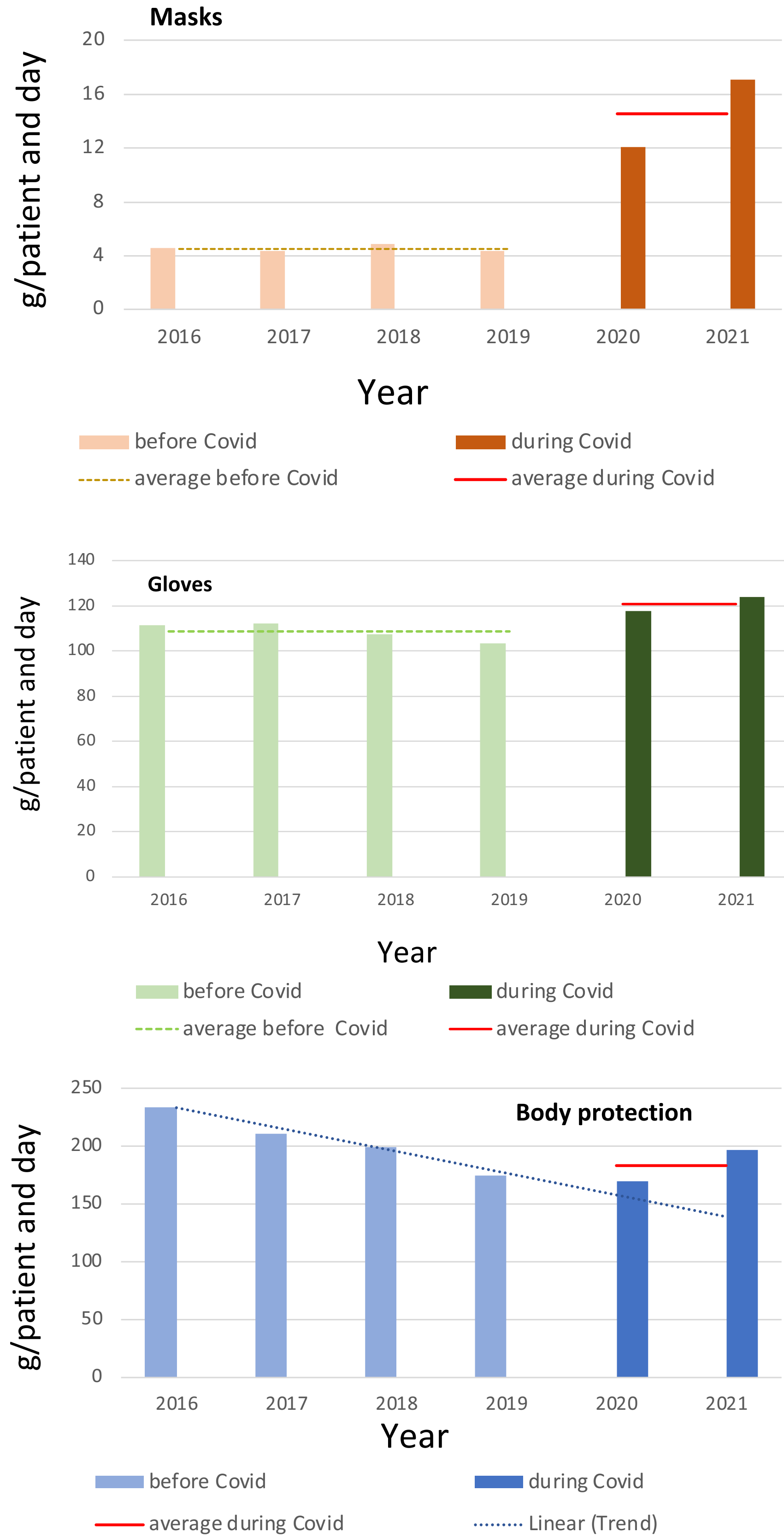

Fig. 4 Total mass of PPE per inpatient day in g/patient: **a** masks, **b** gloves, and **c** body protection

However, if we look at the total mass of PPE, the effect of the pandemic is only small. This is caused by the much higher weight of body protection which dominates at the end the mass of PPE, while masks contribute only a minor share to the total weight. Because the number of body protection items was only slightly influenced by the pandemic, the overall mass of PPE was only increasing slightly. This is somewhat counterintuitive but it shows how important it is to distinguish between the number of items and their actual weight.

For the amount of a consumed resource or the amount of waste, it is not relevant how many single pieces are part of the waste but their weight. Here, we clearly see the results of the effort of the hospital to reduce the amount of heavy PPE and therefore the waste. The pandemic has (in terms of PPE) not resulted in a surge in PPE waste. There was a certain increase but this rather compensated a decrease since the year 2018. We could therefore expect that after Covid the trend toward less PPE mass will continue. However, we also have to consider that the possible options to reduce the weight of PPE is limited and that "low-hanging fruits" have been targeted first, e.g., shifting to thinner aprons.

Besides the Covid effect being a change in the consumption of PPE, it is a combination of changes in the influx of Covid-confirmed patients, changes in the available work force, and bed capacity, all of which are tied to the regulatory response to the pandemic. The lower number of non-Covid patients during the pandemic influenced, for example, the overall use of PPE. We have therefore calculated the mass of PPE per patient and day, providing therefore a value that is generally applicable. This value is about 15 g of masks per patient and day, 120 g of gloves, and 180 g of body protection, resulting in a total about 319 g of PPE per patient and day. Without Covid, we would have expected a value of 264 g per patient and day, considering the continuing decrease in body protection. The Covid effect per patient day is therefore 55 g. We can compare these values to the 619 g per patient and day of all medical polymer consumables used in the same hospital before the pandemic [6]. As stated in that study, PPE contributed 49% to the mass of total consumables. As the total number of medical consumables was not evaluated for the Covid years, we do not know the actual value but can expect that the share of PPE increased by some percent.

As a case study in one hospital, this work clearly has limitations. The most obvious one is related to the specifics of the BG Klinikum Bergmannstrost which was not treating patients for Covid but only with Covid. Still, a lot of the measures that became common during the pandemic were also followed by this hospital. The values in PPE use per patient and the increase during the pandemic should therefore be used with caution when transferring to other hospitals or even whole countries. We also need to consider that the investigated hospital had already taken measures in the last years to reduce the use of medical consumables and the procurement department of the hospital was already very much aware of the problems of single-use items and was working together with the staff on measurements to reduce them. The overall use of PPE may therefore be somewhat lower than in an average hospital; however, legal obligations, for example, to wear a particular type of mask have consequences on all hospitals.

Although we were able to obtain data on all procurements for 6 years, separated into all orders of all articles, we could not use the data as such as it was much too detailed and needed to be categorized and curated. As it was impossible to get accurate weights of all the thousands of different articles, we used representative items to determine the weight and extrapolated to all products within one group. This may have introduced some uncertainty but using as representative articles those with the highest share in group we could minimize the potential influence.

All PPE used will become waste and thus masses used are directly related to the amount of waste produced. Whereas PPE from hospitals is managed as medical waste, the use of masks by the general public lead to environmental pollution through mismanagement and waste littering. Such mismanagement is not possible for medical waste. In the case of the investigated hospital all waste is incinerated due to the policy of the local waste handling authorities and no recycling is allowed. No mismanagement is possible for this case. A small Covid effect on the general resource consumption by the increased use of PPE in the hospital exists. But the direct impacts on the environment through littering of PPE are well mitigated through tight waste management. In that light, the use of PPE by the general public poses a much more pertinent long-term pollution issue.

Future work on the potential of long-term substitution of single-use gowns and aprons by reusable and washable products is interesting in the perspective of life cycle assessment (LCA) to inform the overall environmental performance, the safety performance, and economic effects of the use of PPE. Studies such as the present one are able to provide the basic inventory data to be able to perform such studies.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10163-023-01745-1.

Acknowledgements We would like to address our special thanks to Cornelia Uhlmann (Medical Controlling), Anna Tunack, and Jan Richter (Strategic Corporate Development and Corporate Governance) within the BG Klinikum Bergmannstrost for the provision of the occupancy rates.

Author contributions TI contributed to Conceptualization, Formal analysis, Investigation, Visualization, Writing of the original draft, and Writing, reviewing, and editing of the manuscript. CG contributed to Data curation and Writing, reviewing, and editing of the manuscript. Bernd Nowack contributed to Writing of the original draft, Conceptualization, Writing, reviewing, and editing of the manuscript, Supervision, and Funding acquisition.

Funding Open Access funding provided by Lib4RI – Library for the Research Institutes within the ETH Domain: Eawag, Empa, PSI & WSL. This project was funded by the Federal Ministry of Education and Research (BMBF) of Germany in course of the *PromatLeben—Polymere* research project.

Data availability Data will be made available upon request.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

1. U.S. Food & Drug Administration Personal Protective Equipment (PPE) Available online: https://www.fda.gov/medical-devices/general-hospital-devices-and-supplies/personal-protective-equipment-infection-control. Accessed 16 June 2023
2. Furman E, Cressman A, Shin S, Kuznetsov A, Razak F, Verma A, Diamant A (2021) Prediction of personal protective equipment use in hospitals during COVID-19. Health Care Manag Sci 24:439–453. https://doi.org/10.1007/s10729-021-09561-5
3. Livingston E, Desai A, Berkwits M (2020) Sourcing personal protective equipment during the COVID-19 pandemic Edward Livingston, MD; Angel Desai, MD, MPH; Michael Berkwits, MD MSCE As. JAMA 323:1912–1914. https://doi.org/10.1001/jama.2020.5317
4. Cohen J, van der Meulen Rodgers Y (2020) Contributing factors to personal protective equipment shortages during the COVID-19 pandemic. Prev Med (Baltim) 141:106263. https://doi.org/10.1016/j.ypmed.2020.106263
5. Kumar H, Azad A, Gupta A, Sharma J, Bherwani H, Labhsetwar NK, Kumar R (2020) COVID-19 creating another problem? Sustainable solution for PPE disposal through LCA approach. Environ Dev Sustain. https://doi.org/10.1007/s10668-020-01033-0
6. Ivanović T, Meisel H-J, Som C, Nowack B (2022) Material flow analysis of single-use plastics in healthcare: a case study of a surgical hospital in Germany. Resour Conserv Recycl 185:106425. https://doi.org/10.1016/j.resconrec.2022.106425
7. Ardusso M, Forero-López AD, Buzzi NS, Spetter CV, Fernández-Severini MD (2021) COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.144365
8. Patrício Silva AL, Prata JC, Walker TR, Duarte AC, Ouyang W, Barcelò D, Rocha-Santos T (2021) Increased plastic pollution due to COVID-19 pandemic: challenges and recommendations. Chem Eng J 405:126683. https://doi.org/10.1016/j.cej.2020.126683
9. Asadi S, Cappa CD, Barreda S, Wexler AS, Bouvier NM, Ristenpart WD (2020) Efficacy of masks and face coverings in controlling outward aerosol particle emission from expiratory activities. Sci Rep 10:1–13. https://doi.org/10.1038/s41598-020-72798-7
10. Meier P, Zabara M, Hirsch C, Gogos A, Tscherrig D, Richner G, Nowack B, Wick P (2022) Evaluation of fiber and debris release from protective COVID-19 mask textiles and in vitro acute cytotoxicity effects. Environ Int. https://doi.org/10.1016/j.envint.2022.107364
11. Schmutz M, Hischier R, Batt T, Wick P, Nowack B, Wäger P, Som C (2020) Cotton and surgical masks—what ecological factors are relevant for their sustainability? Sustain 12:1–13. https://doi.org/10.3390/su122410245