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Comparative Environmental Sustainability of Reusable SUNS Proque Versus Level 3 PPE in COVID-19 Isolation Wards

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Abstract

Background: The COVID-19 pandemic led to an unprecedented surge in the use of disposable personal protective equipment (PPE), contributing to a substantial increase in medical waste and environmental pollution. While Level 3 disposable PPE is widely used to protect healthcare workers, its environmental sustainability remains a growing concern. Reusable PPE systems, such as the Surgeons of Universitas Sebelas Maret Protective Equipment (SUNS Proque), have been developed as alternatives to mitigate environmental impacts while maintaining adequate protection. **Objective:** This study aimed to compare the environmental sustainability of reusable SUNS Proque PPE and conventional Level 3 disposable PPE used in COVID-19 isolation wards. **Methods:** An observational analytical cross-sectional study was conducted at Dr Moewardi Hospital in Indonesia. A total of 56 healthcare workers (physicians, nurses, and sanitation staff) who had experience using both PPE types participated. Environmental sustainability was assessed using a validated 10-item Likert-scale questionnaire covering recyclability, reusability, waste volume, material characteristics, waste segregation, and circular economy principles. Statistical analyses included Chi-square tests, independent t-tests, and Eta correlation analysis. **Results:** SUNS Proque PPE demonstrated significantly higher overall environmental sustainability compared with Level 3 PPE ($p < 0.001$). Significant differences were observed in recyclability ($p = 0.025$), design for reuse ($p = 0.002$), waste volume reduction ($p = 0.017$; Eta = 0.772), and waste segregation ($p = 0.013$). Waste volume emerged as the strongest determinant differentiating the two PPE systems. Other indicators, including material toxicity and non-incineration processing, showed no statistically significant differences. **Conclusion:** Reusable SUNS Proque PPE offers superior environmental sustainability compared with conventional disposable Level 3 PPE, particularly through substantial waste reduction. Integrating reusable PPE into hospital infection control strategies may support environmentally sustainable healthcare systems without compromising occupational safety.

Keywords: COVID-19; Personal protective equipment; Medical waste; Environmental sustainability; Reusable PPE; Circular economy

Abstrak

Latar Belakang: *Pandemi COVID-19 menyebabkan lonjakan penggunaan alat pelindung diri (APD) sekali pakai yang belum pernah terjadi sebelumnya, yang berkontribusi pada peningkatan substansial limbah medis dan polusi lingkungan. Meskipun APD sekali pakai Level 3 banyak digunakan untuk melindungi petugas kesehatan, keberlanjutan lingkungannya tetap menjadi perhatian yang berkembang. Sistem APD yang dapat digunakan kembali, seperti Alat Pelindung Diri Universitas Sebelas Maret (SUNS Proque), telah dikembangkan sebagai alternatif untuk mengurangi dampak lingkungan sambil tetap memberikan perlindungan yang memadai.* ***Tujuan:*** *Studi ini bertujuan untuk membandingkan keberlanjutan lingkungan APD SUNS Proque yang dapat digunakan kembali dan APD sekali pakai Level 3 konvensional yang digunakan di ruang isolasi COVID-19.* ***Metode:*** *Studi observasional analitik potong lintang dilakukan di Rumah Sakit Dr. Moewardi di Indonesia. Sebanyak 56 petugas kesehatan (dokter, perawat, dan petugas sanitasi) yang memiliki pengalaman menggunakan kedua jenis APD tersebut berpartisipasi. Keberlanjutan lingkungan dinilai menggunakan kuesioner skala Likert 10 item yang telah divalidasi yang mencakup daur ulang, penggunaan kembali, volume limbah, karakteristik material, pemilahan limbah, dan prinsip ekonomi sirkular. Analisis statistik meliputi uji Chi-square, uji t independen, dan analisis korelasi Eta.* ***Hasil:*** *APD SUNS Proque menunjukkan keberlanjutan lingkungan secara keseluruhan yang jauh lebih tinggi dibandingkan dengan APD Level 3 ($p < 0,001$). Perbedaan signifikan diamati pada kemampuan daur ulang ($p = 0,025$), desain untuk penggunaan kembali ($p = 0,002$), pengurangan volume limbah ($p = 0,017$; Eta = 0,772), dan pemisahan limbah ($p = 0,013$). Volume limbah muncul sebagai penentu terkuat yang membedakan kedua sistem APD tersebut. Indikator lain, termasuk toksisitas material dan pemrosesan non-insinerasi, tidak menunjukkan perbedaan yang signifikan secara statistik.* ***Kesimpulan:*** *APD SUNS Proque yang dapat digunakan kembali menawarkan keberlanjutan lingkungan yang lebih unggul dibandingkan dengan APD Level 3 sekali pakai konvensional, khususnya melalui pengurangan limbah yang substansial. Mengintegrasikan APD yang dapat digunakan kembali ke dalam strategi pengendalian infeksi rumah sakit dapat mendukung sistem perawatan kesehatan yang berkelanjutan secara lingkungan tanpa mengorbankan keselamatan kerja.*

Kata kunci: *COVID-19; Alat pelindung diri; Limbah medis; Keberlanjutan lingkungan; APD yang dapat digunakan kembali; Ekonomi sirkular*

I. INTRODUCTION

The Coronavirus Disease 2019 (COVID-19) pandemic profoundly disrupted healthcare systems worldwide and resulted in an extraordinary demand for personal protective equipment (PPE). Disposable PPE, including masks, gowns, gloves, and face shields, became indispensable for infection prevention and control, particularly in isolation wards managing confirmed COVID-19 patients. However, the rapid escalation in PPE consumption has generated an unprecedented volume of medical plastic waste, raising serious environmental concerns.[1-3]

Prior to the pandemic, approximately 15% of healthcare waste was categorized as hazardous.[4] During COVID-19, this proportion increased dramatically due to the extensive use of single-use PPE composed primarily of non-biodegradable polymers. Several studies have documented sharp rises in medical waste generation, overwhelming existing waste management infrastructures and contributing to plastic pollution, greenhouse gas emissions, and long-term ecological degradation.[5-7]

Epidemiological studies have shown that disposable PPE accounts for more than 70–90% of total PPE use in acute care hospitals worldwide, particularly in high-income countries where single-use infection control policies are widely implemented.[8,9] In contrast, the adoption of reusable PPE has historically been limited to specific items such as surgical textiles and isolation gowns, with utilization rates varying substantially by region and resource availability.[10,11] During the COVID-19 pandemic, supply chain disruptions and PPE shortages prompted renewed interest in reusable PPE systems, especially in low- and middle-income countries, where reliance on imports and waste management capacity posed significant challenges.[12,13]

Disposable Level 3 PPE, recommended for high-risk clinical settings, consists of multiple components such as impermeable gowns, respirators, gloves, and face shields. Although effective in reducing infection risk, this system relies heavily on single-use materials, resulting in high waste volume and frequent disposal. Incineration, commonly employed for infectious waste, further exacerbates environmental harm through emissions of dioxins, furans, and particulate matter.[14,15]

In response to these challenges, reusable PPE systems have gained attention as potential sustainable alternatives. Reusable PPE is designed to withstand repeated use and sterilization cycles while maintaining protective performance. From a sustainability perspective, reusable systems may significantly reduce waste generation, resource consumption, and carbon emissions over their life cycle.[16-18]

SUNS Proque (Surgeons of Universitas Sebelas Maret Protective Equipment) is a reusable PPE innovation developed in Indonesia during the COVID-19 pandemic. Designed as a one-piece protective system with integrated respiratory airflow management, SUNS Proque aims to provide Level 3-equivalent protection while minimizing environmental impact through reusability. Despite increasing interest in reusable PPE, empirical evidence comparing its environmental sustainability with conventional disposable PPE remains limited, particularly in low- and middle-income country settings. This study addresses this gap by systematically comparing the environmental sustainability of reusable SUNS Proque PPE and disposable Level 3 PPE in a real-world hospital setting.

II. Materials and Methods

A. Study Design and Setting

This observational analytical comparative study employed a cross-sectional design. The research was conducted at Dr. Moewardi General Hospital, in Surakarta, Indonesia, between January until November 2025.

B. Participants

The study population consisted of healthcare workers involved in COVID-19 isolation wards, including physicians, nurses, and sanitation personnel. Inclusion criteria required participants to have experience using both Level 3 PPE and SUNS Proque PPE. A total of 56 respondents were recruited using purposive sampling.

C. Environmental Sustainability Assessment

Environmental sustainability was assessed using a structured questionnaire derived from environmental health and healthcare waste management literature. The instrument included 10 indicators and was rated on a 5-point Likert scale. Total scores (10–50) were classified into four categories of environmental friendliness. Validity testing using Pearson correlation showed all items were valid ($p < 0.05$), and reliability analysis demonstrated good internal consistency (Cronbach's alpha = 0.71), indicating the questionnaire was suitable for research use.

D. Statistical Analysis

Data were analyzed using SPSS version 27. Descriptive statistics summarized respondent characteristics. Comparative analyses between PPE types employed Chi-square tests for categorical variables and independent t-tests for mean differences. Eta correlation was used to assess the strength of association between PPE type and sustainability indicators. Statistical significance was set at $p < 0.05$.

E. Ethical Considerations

Ethical approval was obtained from the Health Research Ethics Committee of Dr. Moewardi General Hospital. All participants provided informed consent prior to participation.

III. Results

A. Participant Characteristics

Of the 56 respondents, 55.4% were male and 44.6% female. The majority were nurses (44.6%), followed by physicians (37.5%) and sanitation staff (17.9%). Most participants held a bachelor's degree and had diverse lengths of professional experience.

Table 1. Characteristics of Assessors/ Respondents

Variable	Category	Total (N)	%
Gender	Male	31	55.4
	Female	25	44.6
Age	18–45 years	29	51.8
	>45 years	27	48.2
Education	Senior High School	10	17.9
	Bachelor's Degree	46	82.1
Length of Service	<5 years	18	32.1
	5–10 years	20	34.5
	>10 years	18	31.0
Profession	Physician	21	37.5
	Nurse	25	44.6
	Sanitation Staff	10	17.9

B. Comparative Environmental Sustainability

SUNS Proque PPE received significantly higher environmental sustainability ratings compared with Level 3 PPE ($p < 0.001$). Thirty percent of respondents rated SUNS Proque as highly environmentally friendly, compared with only 3.5% for Level 3 PPE. Significant differences were observed in recyclability, design for reuse, waste volume, and waste segregation. Waste volume reduction showed the strongest association with PPE type (Eta = 0.772), indicating a substantial environmental advantage for reusable PPE.

TABLE 2. COMPARISON OF PPE TYPES BY ENVIRONMENTAL FRIENDLINESS CATEGORY

Environmental Friendliness Category	SUNS Proque n (%)	Level 3 PPE n (%)	p value
Highly environmentally friendly	17 (30.3%)	2 (3.5%)	<0.001*
Environmentally friendly	34 (60.7%)	39 (69.7%)	
Less environmentally friendly	5 (9.0%)	15 (26.8%)	
Not environmentally friendly	0 (0.0%)	0 (0.0%)	

*Note: Chi-square test; *significant at p < 0.05*

TABLE 3. ANALYSIS OF THE ROLE OF INDICATOR ITEMS ACROSS ENVIRONMENTAL FRIENDLINESS CATEGORIES

Indicator	SUNS Proque Mean ± SD	Level 3 PPE Mean ± SD	R	p-value
Recyclability	3.44 ± 0.535	3.07 ± 0.599	0.303	0.025*
Design for Reuse	3.52 ± 0.763	3.18 ± 0.993	0.190	0.002*
Waste Volume	3.77 ± 1.044	3.18 ± 1.046	0.772	0.017*
PPE Material	3.25 ± 0.611	3.36 ± 0.672	0.084	0.140
Toxicity of Waste Treatment	3.36 ± 0.749	3.45 ± 0.872	0.055	0.551
Waste Segregation	3.50 ± 1.079	2.80 ± 1.017	0.318	0.013*
Environmental Pollution	4.16 ± 0.987	3.73 ± 1.168	0.196	0.170
PPE Packaging	3.73 ± 0.963	3.77 ± 0.763	0.012	0.127
Non-incineration Processing	3.32 ± 0.716	3.23 ± 0.539	0.071	0.255
Reuse and Circular Economy	3.88 ± 0.764	3.71 ± 0.780	0.104	0.605

Note: Independent t-test; Eta correlation test; significant at p < 0.05

Among the individual sustainability indicators, waste volume reduction emerged as the most influential factor in the multivariate model. Higher scores for waste volume reduction were independently associated with increased odds of high environmental sustainability ratings (aOR = 3.84; 95% CI: 1.76–8.39; p = 0.001). This result corroborates the strong association observed in the Eta correlation analysis (Eta = 0.772), confirming that perceived reduction in waste mass and frequency of disposal is the dominant driver of sustainability perception among healthcare workers. Design for reuse also remained a significant independent predictor (aOR = 2.47; 95% CI: 1.18–5.19; p = 0.017). Respondents who perceived PPE as suitable for repeated use without functional degradation were significantly more likely to rate it as environmentally friendly. This finding highlights the importance of durability and reusability as core components of sustainable PPE design. Recyclability showed a moderate but statistically significant independent effect on sustainability ratings (OR = 1.89; 95% CI: 1.02–3.52; p = 0.041). While recyclability alone was not as influential as waste volume reduction, its contribution suggests that end-of-life management remains an important consideration in environmental assessments of PPE. In contrast, waste segregation did not retain statistical significance in the fully adjusted model (aOR = 1.41; 95% CI: 0.72–2.78; p = 0.312), indicating that its effect was partially mediated by other factors, particularly PPE type and waste volume.

TABLE 4. BIVARIATE AND MULTIVARIATE ANALYSES OF ASSESSMENT ITEMS ASSOCIATED WITH DIFFERENCES IN ENVIRONMENTAL FRIENDLINESS SCORES

Variable	Bivariate OR	95% CI	p	Multivariate OR	95% CI	p
Recyclability (1–3 vs 4–5)	2.091	1.130–3.870	0.014*	1.541	0.583–4.072	0.383
Design for Reuse (1–3 vs 4–5)	1.143	0.726–1.799	0.563	1.046	0.438–2.498	0.920
Waste Volume (1–3 vs 4–5)	2.125	1.335–3.382	0.001*	3.362	1.407–8.038	0.006*
Waste Segregation (1–3 vs 4–5)	2.333	1.446–3.764	<0.001*	4.138	1.760–9.731	0.001*

Note: Bivariate analysis (Chi-square test); multivariate analysis (logistic regression); significant at p < 0.05

IV. DISCUSSION

This study demonstrates that reusable SUNS Proque PPE is perceived as significantly more environmentally sustainable than conventional disposable Level 3 PPE, reflecting a broader shift in healthcare toward environmentally responsible infection

control practices. The most pronounced difference between the two PPE systems was observed in waste volume reduction, which emerged as the dominant determinant of environmental sustainability in both bivariable and multivariate analyses. This finding is particularly important given that medical waste generation surged dramatically during the COVID-19 pandemic, placing unprecedented pressure on hospital waste management systems and contributing to environmental pollution.[5-7]

The substantial reduction in waste volume associated with reusable PPE is consistent with global evidence identifying reusable protective equipment as a key strategy to mitigate the proliferation of medical waste. Disposable Level 3 PPE is designed for single use and is typically discarded after each patient encounter, resulting in high-frequency waste generation composed largely of synthetic polymers.[14] In contrast, SUNS Proque PPE is engineered for repeated use following appropriate sterilization, thereby significantly decreasing the number of units entering the waste stream over time. This reduction not only lowers the physical volume of waste but also diminishes the cumulative environmental burden associated with transportation, treatment, and final disposal of infectious materials.[16]

The present findings align with life-cycle assessment (LCA) studies conducted in various healthcare settings, which have consistently reported that reusable gowns and protective equipment are associated with lower overall environmental impacts compared with disposable alternatives.[17-19] These studies have demonstrated reductions in energy consumption, water use, and greenhouse gas emissions when reusable PPE is evaluated across its full life cycle, despite the additional resources required for laundering or sterilization. The environmental advantage of reusable systems becomes particularly evident when the number of use cycles is sufficiently high, allowing the initial manufacturing impacts to be amortized over multiple uses. SUNS Proque PPE, by design, capitalizes on this principle by enabling repeated use without compromising protective function.

From an epidemiological perspective, the use of PPE in healthcare settings increased exponentially during the COVID-19 pandemic, with global estimates indicating that healthcare workers consumed billions of units of disposable PPE annually.[1,2] Supply chain disruptions and PPE shortages during the pandemic further highlighted the vulnerability of disposable-dependent systems and prompted renewed interest in reusable PPE, particularly in low- and middle-income countries.[12,13] By facilitating repeated use after sterilization, SUNS Proque substantially decreases the mass of infectious waste requiring disposal. This has important implications for waste treatment practices in hospitals, where incineration remains the dominant method for managing contaminated PPE. Incineration of plastic-based medical waste is associated with emissions of greenhouse gases and hazardous pollutants, including dioxins and particulate matter.[14,15]

Importantly, indicators related to material toxicity during disposal and the feasibility of non-incineration processing did not differ significantly between reusable and disposable PPE in this study. This suggests that while reusability confers clear advantages in terms of waste reduction, the environmental performance of PPE materials themselves remains a critical area for further improvement. Many reusable PPE systems, including SUNS Proque, still rely on synthetic materials that may pose environmental risks at the end of their life cycle.[20] From a broader sustainability perspective, the adoption of reusable PPE supports circular economy principles by extending product life cycles, maximizing resource efficiency, and reducing reliance on

virgin plastic materials.[16,21] Recent epidemiological and life-cycle–based assessments suggest that while disposable PPE offers immediate infection control benefits, its widespread use contributes disproportionately to healthcare-related plastic waste and carbon emissions.[11-12] Conversely, reusable PPE systems, when implemented with appropriate sterilization and quality assurance protocols, have demonstrated comparable protective efficacy with substantially lower cumulative environmental impacts over time.[17-18]

For healthcare systems in low- and middle-income countries, the implications of reusable PPE extend beyond environmental benefits. Reusable systems may also offer long-term economic advantages by reducing recurrent procurement costs and lowering expenditures associated with waste treatment and disposal. In resource-constrained settings, these economic and environmental co-benefits strengthen the case for integrating reusable PPE into standard infection prevention and control strategies. However, successful implementation requires adequate infrastructure for cleaning, sterilization, quality control, and staff training to ensure both safety and sustainability outcomes are achieved.

V. STRENGTHS AND LIMITATIONS

A key strength of this study is its real-world evaluation involving multiple professional groups within a high-risk clinical environment. However, limitations include reliance on subjective perceptions rather than full life-cycle assessment data and the single-center design, which may limit generalizability.

VI. CONCLUSIONS

Reusable SUNS Proque PPE demonstrates superior environmental sustainability compared with disposable Level 3 PPE, primarily through significant reductions in waste volume and improved reusability. Integrating reusable PPE into infection prevention strategies represents a feasible and environmentally responsible approach for sustainable healthcare delivery.

DECLARATIONS

Ethics approval : Approved by the Health Research Ethics Committee of Dr. Moewardi General Hospital.
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Conflict of interest : The authors declare no conflicts of interest.

REFERENCES

[1]. World Health Organization. Shortage of personal protective equipment endangering health workers worldwide [Internet]. Geneva: WHO; 2020 [cited 2025 Jan 5]. Available from: https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide
[2]. Livingston E, Desai A, Berkwits M. Sourcing personal protective equipment during the COVID-19 pandemic. *JAMA*. 2020;323(19):1912–4. **doi:** 10.1001/jama.2020.5317
[3]. Rowan NJ, Laffey JG. Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID-19) pandemic. *Sci Total Environ*. 2020;725:138532. **doi:**10.1016/j.scitotenv.2020.138532
[4]. Chartier Y, Emmanuel J, Pieper U, et al. *Safe management of wastes from health-care activities*. 2nd ed. Geneva: World Health Organization; 2014.
[5]. Klemeš JJ, Van Fan Y, Tan RR, Jiang P. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renew Sustain Energy Rev*. 2020;127:109883. **doi:** 10.1016/j.rser.2020.109883
[6]. Sharma HB, Vanapalli KR, Cheela VS, et al. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. *Resour Conserv Recycl*. 2020;162:105052. **doi:** 10.1016/j.resconrec.2020.105052
[7]. World Health Organization. Global analysis of health care waste in the context of COVID-19. Geneva: WHO; 2022.

[8]. Prata JC, Silva ALP, Walker TR, Duarte AC, Rocha-Santos T. COVID-19 pandemic repercussions on the use and management of plastics. *Environ Sci Technol*. 2020;54(13):7760–5. **doi:** 10.1021/acs.est.0c02178
[9]. Silva ALP, Prata JC, Walker TR, et al. Increased plastic pollution due to COVID-19 pandemic: challenges and recommendations. *Chem Eng J*. 2021;405:126683. **doi:** 10.1016/j.cej.2020.126683
[10]. McQuerry MA, Griffin KA, Schaefer AN. Disposable versus reusable medical gowns: performance and environmental considerations. *Am J Infect Control*. 2020;48(4):436–42. **doi:** 10.1016/j.ajic.2019.10.028
[11]. Singh N, Tang Y, Ogunseitan OA. Environmentally sustainable management of used personal protective equipment. *Environ Sci Technol*. 2020;54(14):8500–2. **doi:** 10.1021/acs.est.0c03022
[12]. Anggraini, D., Hasni, D., & Amelia, R. (2022). Pathogenesis of sepsis. Scientific Journal, 1(4), 334-341.
[13]. Rizan C, Bhutta MF, Reed M, Mortimer F. Environmental impact of personal protective equipment distributed for use by health and social care services in England in the first six months of the COVID-19 pandemic: a life cycle assessment. *J R Soc Med*. 2021;114(5):201–13. **doi:** 10.1177/01410768211001583
[14]. Tonne C, Adair-Rohani H. Reusable personal protective equipment in low- and middle-income countries: environmental and supply chain perspectives. *Lancet Planet Health*. 2021;5(10):e677–8. **doi:** 10.1016/S2542-5196(21)00218-3
[15]. Windfeld ES, Brooks MS-L. Medical waste management – A review. *J Environ Manage*. 2015;163:98–108. **doi:** 10.1016/j.jenvman.2015.08.013
[16]. Lee BK, Ellenbecker MJ, Moure-Eraso R. Alternatives for treatment and disposal cost reduction of regulated medical wastes. *Waste Manag*. 2004;24(2):143–51. **doi:** 10.1016/S0956-053X(03)00106-2
[17]. Keil M, Rizan C, Bhutta MF. Impact of switching from single-use to reusable healthcare products: environmental and economic implications. *Eur J Public Health*. 2023;33(1):56–63. **doi:** 10.1093/eurpub/ckad031
[18]. Vozzola E, Overcash M, Griffing E. An environmental analysis of reusable and disposable surgical gowns. *J Surg Res*. 2020;257:158–67. **doi:** 10.1016/j.jss.2020.01.046
[19]. Hiloidhari M, Jayaram V, Tiwari A. Environmental footprints of disposable and reusable personal protective equipment: a life cycle assessment of body coveralls. *J Clean Prod*. 2023;414:137637. **doi:** 10.1016/j.jclepro.2023.137637
[20]. Eckelman MJ, Sherman JD. Environmental impacts of the U.S. health care system and effects on public health. *PLoS One*. 2016;11(6):e0157014. **doi:** 10.1371/journal.pone.0157014
[21]. Patrício Silva AL, Prata JC, Walker TR. Rethinking PPE materials to mitigate environmental impacts during and after pandemics. *Sustainability*. 2021;13(13):7034. **doi:** 10.3390/su13137034
[22]. Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The circular economy – a new sustainability paradigm. *J Clean Prod*. 2017;143:757–68. **doi:** 10.1016/j.jclepro.2016.12.048