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Medical Gown Disposal Options from the Environmental Life Cycle Perspective

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The existing COVID-19 pandemic has driven personal protective equipment use and consumption surge, leading to plastic pollution as most waste goes to landfills. Biodegradable polypropylene (PP) gowns claimed to have similar production costs as standard PP film ones might be more environmentally friendly due to the degradability after landfilling. The illustration of their sustainable end-of-life waste disposal options is lacking and requires a systematic comparison of their environmental impacts. A holistic life cycle assessment approach based on full-spectrum environmental indicators identifies the environmentally sustainable waste disposal options. Results illustrate the environmental benefits of landfill gas capture and utilization incorporated to landfilling biodegradable gown wastes by reducing 48.81 % land-use, 9.35 % greenhouse gas emissions from fossil sources, and 5.67 % from land-use greenhouse gas emissions, respectively. Despite these environmental advantages, industrial composting embodies lower environmental emissions than sanitary landfills for treating biodegradable gowns. Fossil-based gowns treated by landfills can have lower environmental impacts than composting biodegradable gowns in full-spectrum environmental indicators. The standard gown landfilling is identified as the environmentally sustainable disposal option.

1. Introduction

A surge in plastic gown consumption due to COVID-19 has driven plastic gown production (Zhao et al, 2021). As a measure for effective control over the spread of COVID-19, medical staff has instead started using disposable gowns over reusable ones (Tao et al., 2021). In an interim estimate of U.S. personal protective equipment (PPE) needs for COVID-19, John Hopkins reported that a single 100 d COVID-19 wave would require an additional 321 M isolation gowns along with baseline isolation gowns for use in hospitals, emergency departments, medical services, outpatient visits and nursing homes in U.S. alone (Toner, 2020). This gown manufacturing expansion will push fresh strains on waste management sectors (Bennett et al., 2019), including composting, landfill, and incineration, and pose environmental hazards associated with air (Hou et al., 2018), soil (Deshpande et al., 2020), water (Antelava et al., 2019), and ecosystems (Garcia et al., 2019) if wastes are mismanaged. Given the main use in plastic waste management (Hou et al., 2021), easy operation, and relatively low GHG emissions compared to the incineration process (Tang, 2018), landfills are used for gown waste treatment (Chin et al., 2022), and other plasticized gown waste-related end-of-life processes, like chemical recycling technologies, are not as widely used as landfills because of the higher capital and operating costs in real-world application (Fan et al., 2022).
Standard medical gowns made from fossil-based polypropylene (PP) typically end up in landfills where the plastic wastes undergo chronic degradation and pose freshwater ecotoxicities (Demetrious and Crossin, 2009). Biodegradable gowns have similar production costs to standard one can gain environmental benefits from sustainable disposal options (Babaahmadi et al., 2021). The biodegradable plasticized gown is made of plastics and the doped pro-oxidant ensures biodegradability and compostability (Sable et al., 2021). Soil organisms can crack these gowns within short terms (30 y) through technologies (such as composting) and yield GHGs from non-sequestrated carbon emissions (Kim et al., 2022) while keeping methane production minimum. Weighing conventional medical gowns' environmental advantages and drawbacks against biodegradable counterparts and their sustainable disposal options are still lacking in existing studies.

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Life cycle assessment (LCA) can be powerful in systematically evaluating the environmental performances of gown waste disposal processes (Zhao et al., 2022). Existing plastic waste LCA studies on end-of-life process choices (Bora et al., 2020) and environmental indicators selection can be referred to when assessing long-term and short-term environmental impacts of both fossil-based and biodegradable medical gowns. The environmentally sustainable gown waste disposal options are then determined through comparative evaluations to provide technical insight on waste management sectors and guidance for judicious selection of medical gown suppliers to suppress environmental issues from manufacturing sectors. The environmental implication interpreted from our study could also be extrapolated to other plastic products, given their similar chemical nature to disposable gowns.

2. LCA methodologies

This work identifies the environmentally sustainable gown waste disposal options by assessing their environmental impacts through a process-based LCA approach. Four phases are required: Goal and scope definition, life cycle inventories (LCIs), impact assessment, and interpretation. This LCA aims to determine the environmentally sustainable gown waste disposal options by systematically comparing full-spectrum environmental performances of biodegradable and standard plastic gowns aided by a rigorous LCA framework (Tian et al., 2020). The "cradle-to-grave" system boundary for standard gowns includes raw material extraction, naphtha cracking (propylene production), polypropylene production, gown fabrication, use phase, truck transportation, and landfills. Biodegradable gowns differ from standard gowns in the end-of-life phase (composting) and chemical additives (CoSt photo-prooxidants) that catalyze biodegradation. The landfill gas (LFG) capture and utilization were not accounted for in landfilling standard (fossil-based) gowns, given negligible LFG emissions within centuries (Bora et al., 2022). The functional unit is chosen as 1 t waste gowns treated to align the mass and energy flow information among life cycle stages (Yang et al., 2018).

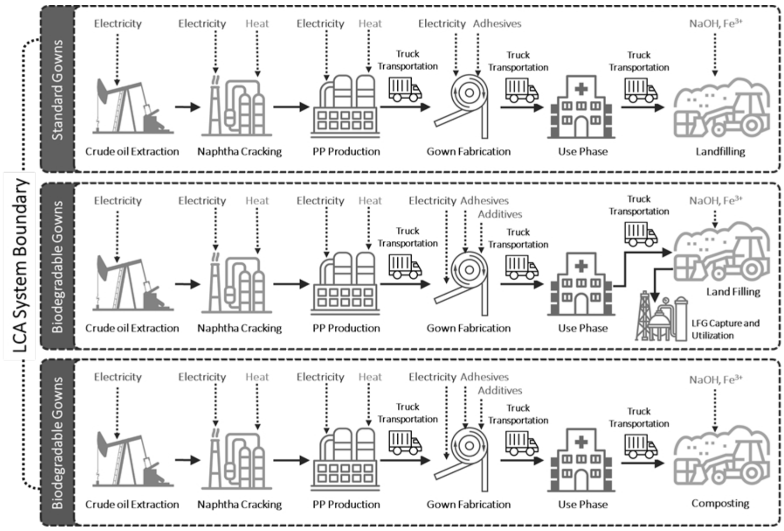

Figure 1: The "cradle-to-grave" system boundary of this LCA study regarding standard gown waste landfilling, biodegradable gown waste landfilling, and biodegradable gown waste composting

The upstream LCIs were collected from the mass and energy flow rates within the raw material (crude oil and natural gas) extraction, PP production, gown fabrication, use phase (no reuse for disposable gowns), waste sterilization, and transportation. The energy and chemical use for the packaging based on the amount of packaging used per gown was also considered in the study, and the respective mass (Vozzola et al., 2020) and energy balances (Burguburu et al., 2022) were taken from the literature. The energy consumption in pretreating the medical gown wastes was collected from the literature (McGain et al., 2016). The total gown waste transportation distance was also calculated by the sum of distances between the landfilling sites and the medical care locations. The LCIs were built based on mass and energy balances regarding chemical and energy inputs for landfilling operation (Time horizon: 60 y), leachate treatment, LFG capture, and utilization processes within the system boundary. Ecoinvent V3.8 Database and existing related literature were employed to extract the LCI data corresponding to landfilling operation and leachate treatment processes (Demetrious and Crossin, 2009). The LFG yielded from decomposing biodegradable is mainly CH_4 and CO_2 and is used to generate medium-voltage electricity sent directly to the electric grid (Zhao, 2022). The avoided burden approach was applied to account for the environmental benefit from this onsite electricity generation (Zhao, 2021). Those environmental impacts were subtracted from the total environmental assessment results. LCIs of gown waste composting were built based on the operating data and chemical compositions of gas emissions of industrial composting processes, which are typical disposal options for biodegradable plastic wastes. The gas emissions data are assumed to be the average from composting eight biodegradable materials from relevant literature (Hermann et al., 2011). The composting duration was calculated as four years when the biodegradable plasticized gowns are fully degraded into carbon dioxide based on the chemical reaction kinetics given in Sable et al. (2021) and no specific application or disposal of the compost is considered. The operation LCI data were extracted from the industrial composting process data within Ecoinvent V3.8 Database (cut-off).

All compiled LCI data were then interpreted into environmental assessment results aided by environmental indicators corresponding to air, water, soil, and ecotoxicity to reflect plastic and chemical pollution in these compartments. Product-level indicators, including EF 3.0, are widely used in plastic processing LCA studies and can be adopted to overview the full-spectrum environmental aftermaths caused by gown production and waste disposal (Bishop et al., 2021). The ReCiPe-based indicators in different time-horizon perspectives (20 y for individualist, 100 y for hierarchist, and 500 y for egalitarian perspectives) were also adopted to account for the short and long-term emissions from waste landfilling and composting processes. The carbon footprints from gown wastes were calculated based on the global warming potential (GWP) indicators for 20 y, 100 y, and 500 y extracted from the IPCC 2013 life cycle impact assessment method given in Ecoinvent V3.8 Database.

The environmental impact assessment results were then summed up for all life cycle stages and compiled into environmental profiles in various impact indicators to show their hotspots (Tian et al., 2021). Illustrations of environmental hotspots can guide selecting environmentally sustainable gown waste disposal processes, while the environmentally sustainable disposal options can be identified by comparing their absolute impact assessment results.

3. Results and discussion

The life cycle environmental impacts of standard gown wastes treated by landfill processes based on full-spectrum EF 3.0 indicators are overviewed in Figure 2. The gown production process is identified as the environmental hotspot for all impact categories except the non-carcinogenic human toxicity effects caused by organic chemical emissions, ozone depletion, and particulate matter formation, given the high production and consumption rates of packaging materials and chemicals for treating leachates. High fossil fuel consumption in transporting basic materials can pose pronounced environmental impacts corresponding to organic chemical emissions, including 95.87 % of non-cancer human toxicity, 88.64 % ozone depletion, and 89.67 % particulate matter formation effects. Assessing short- and long-term environmental impacts can enforce sustainable gown production and disposal decisions due to different environmental impacts of LFG emissions in various time horizons. Figure 3 illustrates that the waste treatment via sanitary landfills, however, causes less short- and long-term environmental emissions than gown production. Given the same environmental hotspots as Figure 2, environmentally sustainable gown production and end-of-life waste treatment for fossil-based gowns are critical.

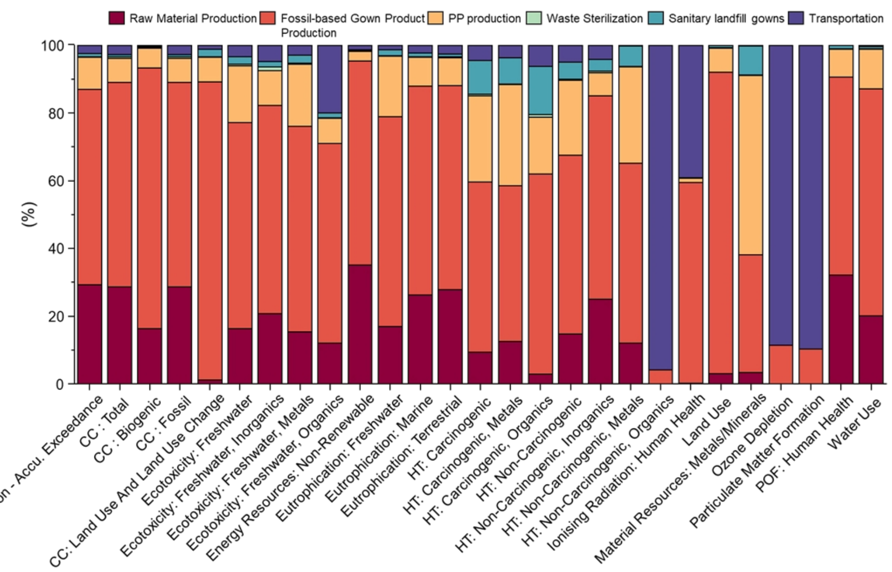

Figure 2: Environmental profile for standard gowns landfilling based on EF 3.0 indicators

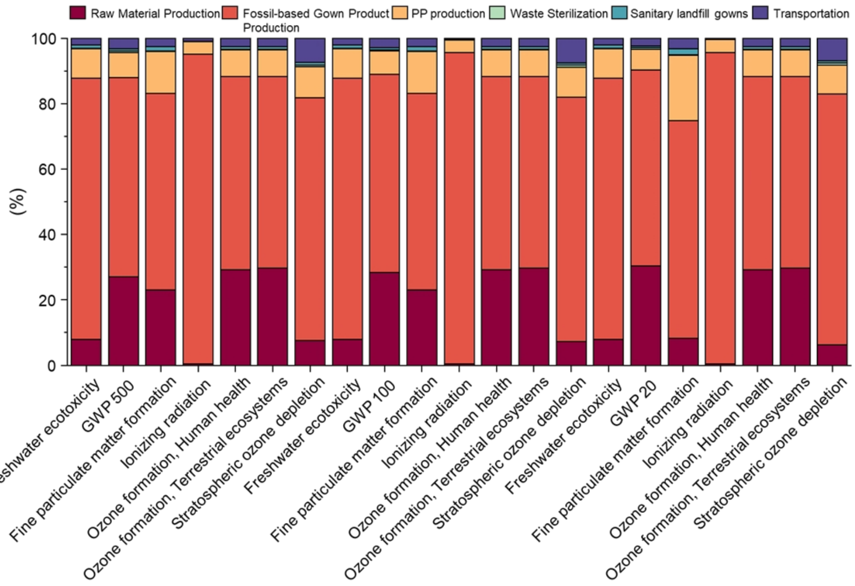

Figure 3: Environmental profile for standard gowns landfilling based on ReCiPe, USEtox, and GWP indicators

Identifying the sustainable waste disposal options for both gowns can imply future technical innovations in waste management sectors and guide the judicious selection of medical gown suppliers from the environmental sustainability perspective. Figures 4 and 5 displays the higher life cycle environmental impacts of biodegradable gown wastes treated by composting than standard gowns ending up in landfills based on all full-spectrum EF 3.0 impact categories, especially the biogenic GHG emissions and ecotoxicity effects caused by organic chemical emissions. The uncaptured CO_2 emissions from industrial composting can lead to this higher climate change potential, while the solvent production used for chemical additive production increases organic ecotoxicity problems from the whole life cycle of biodegradable gowns. Future investigations on the environmentally sustainable gown or plastic waste disposal can focus on reducing the GHG emissions from industrial composting processes or leachate emission mitigation from the landfilling standard gowns.

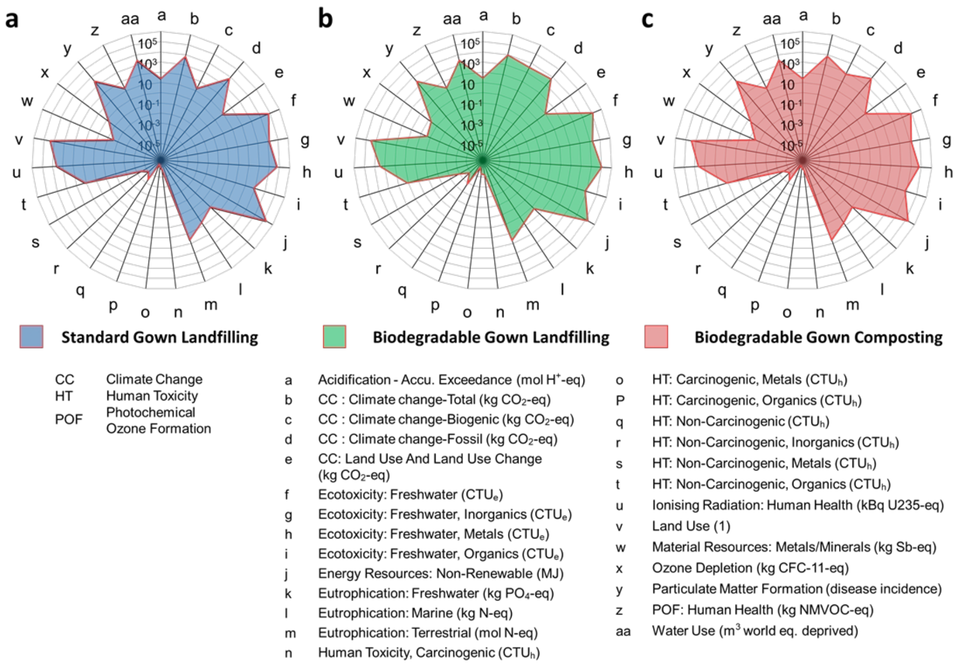

Figure 4: EF 3.0-based environmental assessment results of disposal options for medical gowns: a. Standard Gown Landfilling. b, Biodegradable Gown Landfilling. c, Biodegradable Gown Composting

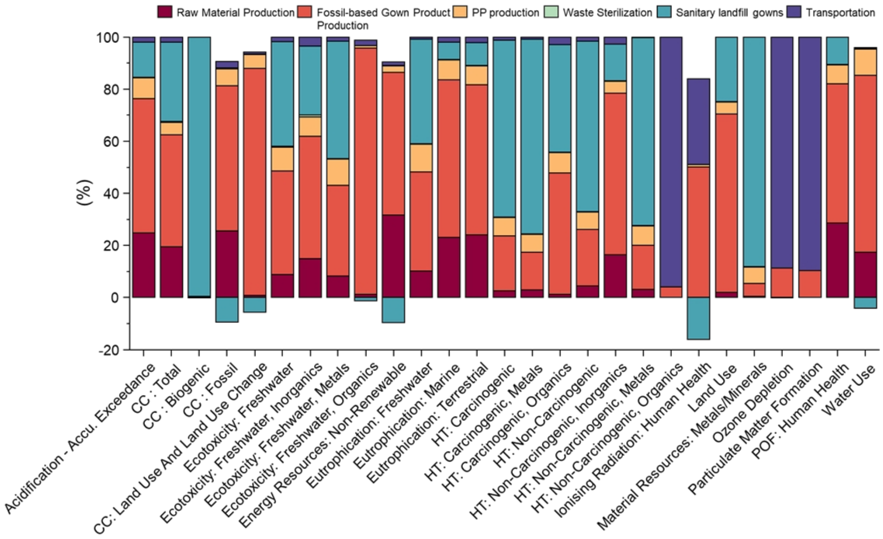

Figure 5: Environmental breakdowns for biodegradable gowns landfilling based on EF 3.0 indicators

4. Conclusion

This work performed a "cradle-to-grave" LCA on standard and biodegradable gown wastes treated by different disposal processes to identify sustainable waste disposal options. Results showed the full-spectrum environmental hotspots on gown production and end-of-life disposal of biodegradable gowns and illustrated the sustainability benefits of LFG capture and utilization processes corresponding to 48.81 % land-use and 9.35 % and 5.67 % GHG emissions reduction regarding fossil sources and land-use, respectively. These environmental advantages could not offset the extra emissions from process infrastructures and operations compared to composting. Comparative results on standard gown landfill processes with this industrial composting based on full-spectrum environmental indicators demonstrated the environmental sustainability of landfilling fossil-based gowns. Future investigations on environmentally sustainable gowns or plastic waste disposal can focus on reducing the GHG emissions from industrial composting processes or leachate emission mitigation from the landfilling standard gowns. Future studies will consider a hybrid LCA approach to deal with expanded system boundaries (Yue et al., 2014), introduce a consequential perspective to the analysis (Zhao and You, 2021), and also investigate the environmental impacts of plastic losses sourced from biodegradable gown waste to stress and address the debris environmental issue from gown waste end-of-life management options.

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