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Ecological footprint of salbutamol administration by metered-dose inhaler versus nebulisation in acute asthma: a life-cycle assessment

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Summary

Objective: The scientific evidence indicates little or no difference in the effectiveness or cost of using of metered-dose inhalers (MDIs) versus nebulisation to treat acute asthma in the emergency department (ED). However, the use of MDIs raises questions of environmental impact. Our objective was to compare the ecological footprint of salbutamol administered by MDI versus nebulisation.

Design: Life cycle assessment in which we inventoried and quantified the resources extracted and pollutants emitted by each therapeutic option, from the manufacturing of medication and equipment to their disposal by incineration.

Setting: EDs of the CHU de Québec-Université Laval (Canada).

Participants: Not applicable.

Main outcome measures: Each item of life cycle inventory data was translated into CO₂-equivalent emissions (CO₂eq) using the IPCC2021/GWPI00 method. Results were estimated for the administration of one and three treatments of 800 µg of salbutamol by MDI and 5 mg by nebulisation (standard doses for adults and children ≥ 24 kg).

Results: One and three ED-administered treatments with salbutamol emit respectively 1.9 and 4.0 kg of CO₂eq via MDI versus 0.9 and 1.0 kg via nebulisation, which corresponds to 5.5 and 11.6 km and to 2.7 and 2.8 km travelled in a subcompact car. Each series of eight inhalations from an MDI releases 1.1 kg of CO₂eq due to emission of the hydrofluoroalkane propellant.

Conclusions: Considering the absence or minimal difference in clinical effectiveness, this study suggests that nebulisation may be a more eco-efficient administration route than

MDIs in the emergency treatment of asthma.

Trial registration: N/A

Keywords

acute asthma, emergency department, ecological footprint, life cycle assessment

Introduction

Healthcare services are responsible for 4.6% of greenhouse gas emissions worldwide.¹ The USA and Canada rank first and third, respectively, in per capita healthcare-related emissions of CO₂ equivalents (CO₂eq).¹ Increasing emissions of greenhouse gases contribute to global warming, of which the negative impact on human health includes an increase in heat-related illnesses and respiratory problems as well as wider spread of infectious diseases.²

The use of metered-dose inhalers (MDIs) to administer bronchodilators (e.g. salbutamol) is considered a significant source of health-service-associated greenhouse gas emissions.³ It has been estimated that in the United Kingdom, up to 13% of such emissions result from the use of MDIs to treat asthma or chronic obstructive pulmonary disease (COPD). The main greenhouse gas emitted from these devices is the hydrofluoroalkane (HFA) propellant. Some HFAs have atmospheric warming potentials up to 3000 times that of CO₂.^{4,5} Consequently, replacing MDIs with HFA-free administration methods is regarded as desirable whenever possible. However, MDI

use has become the standard of care in many EDs.^{6,7} Administration of a bronchodilator in the form of fine droplets is the main therapeutic alternative in the hospital setting. This mode, known as nebulisation, is said to have clinical effectiveness comparable to MDIs for key clinical outcomes such as hospital admission or Forced Expiratory Volume in One Second (FEV₁), although MDIs are associated with a shorter ED length of stay and fewer tremors in pediatrics.⁸ To our knowledge, the environmental impact of nebulisation in the ED setting has not been evaluated and compared with that of MDIs.⁵

The objective of this study was to compare the environmental footprints of MDI and nebulisation when used to administer salbutamol to adults in EDs.

Methods

Design and setting

This is an observational study comparing MDIs and nebulisation as methods of administering salbutamol to asthmatic patients in EDs, using a life cycle assessment methodology to calculate the 'cradle to grave' environmental footprints (e-Figure 1). The study was conducted during fiscal year 2022–2023 at the CHU de Québec-Université Laval (hereafter the CHU), an academic institution that manages five EDs located throughout Québec City (Canada) and receiving more than 240,000 visits annually.

Life cycle assessment

We evaluated an MDI (100 µg of salbutamol/dose, 200 doses) and a nebulisation ampoule (5 mg/mL, 10 mL), both products manufactured by GSK. An MDI is for single-patient use, whereas multiple patients can be treated with a single nebulisation ampoule.

The assessment followed ISO standards 14,040 and 14044^{9,10} and consisted of four phases:

1. Definition of the goal, scope, and functional unit

We compared one and three administrations of a standard dose of salbutamol in the ED for adults and children weighing ≥ 24 kg, namely 800 µg (eight puffs) via MDI and 5 mg (1 mL) via nebulisation (functional unit). The life cycle assessment included production, packaging, transportation, use in the ED, and incineration, assuming all material disposal takes place at the hospital. We considered MDI treatments with a reusable plastic spacer or a single-use cardboard spacer, as well as all the reusable material (nebulising cup, plastic tubing, and oxygen mask) required for nebulisation.

2. Life cycle inventory

We decomposed the life cycles of the two therapeutic options to identify all emissions and extractions within the

system boundaries. In addition to the product monographs, we obtained the inventory data for all components of the MDI, plastic and cardboard spacers, nebulisation ampoule and materials using attenuated total reflectance infrared spectroscopy, which provides detailed information about the molecular composition of a product. The composition of the MDI canister gas was analysed using multinuclear nuclear magnetic resonance and gas-phase infrared spectroscopies. The methods for identifying the volatile components are described in e-Appendix 1. The production plants were located using procurement information obtained from our institution. The road distance to the biomedical waste management company used by the CHU (Stericycle) was determined. The complete life cycles were modelled using the openLCA software and the ecoinvent life cycle inventory database (version 3.9.1) and adapting some processes to the Québec context.

3. Impact assessment and outcome measures

The inventoried emissions and extractions were translated into environmental indicators in the following impact categories: (i) *Climate change*, in kg of CO₂ equivalent emissions (CO₂eq); (ii) *Human health*, in disability-adjusted life-year (DALY) loss; (iii) *Fossil resources use*, in megajoules (MJ) deprived; and (iv) *Ecosystem quality*, in potentially disappeared fraction of species (PDF) over square meter years (PDF·m²·year). The human health and ecosystem quality indicators aggregate a series of intermediate effects of the production, use, and disposal of asthma treatment products. The inventory data were converted into impact units using the validated assessment method IPCC2021 GWP100 for *Climate change* and the IMPACT World + method for the other impact categories.

4. Interpretation of results

The indicator results were interpreted relative to the functional units for one or three administrations, which are common initial prescriptions for asthma treatment in many ED protocols. Hotspots were identified, that is, the life cycle elements having the highest contribution to the indicator.

Alternative scenarios and extrapolations. Patients discharged from the CHU EDs are often allowed to keep the MDI for use at home. We considered this alternative scenario in the model by assuming that all such MDIs were emptied and ended up in the same incinerator as if they had been left in the ED.

We also estimated the annual environmental footprint of the asthma treatments based on medication consumption recorded at the CHU during 2022–2023. Since it

was not possible to retrace the number of administrations and the dosages for each patient treated with an MDI, we assumed a minimum of three administrations of 800 µg (eight inhalations) for each MDI delivered by the pharmacy to the ED during the study period.

Statistical analysis

The life cycle inventory and impact assessment calculations were performed in openLCA (GreenDelta, version 2.4.1) using the ecoinvent database (v.3.9.1 cut-off by classification, published in 2023) to model the background processes (materials production, energy generation, transport and waste treatment). We report the results as point estimates and stacked bar charts, in accordance with the standards used for life cycle assessment reporting. To account for the uncertainties of the proxies used in the inventory, we conducted a Monte Carlo simulation with 1000 iterations. Uncertainty for each inventory flow was characterised using the Pedigree Matrix approach,¹¹ which evaluates data quality across five domains (reliability, completeness, temporal, geographical, and technological representativeness). For the foreground processes we modelled specifically for this study, the investigator-assigned ratings were converted into geometric standard deviations and applied as log-normal distributions. For the background processes, the ecoinvent datasets already included these distributions, which were then used directly in the Monte Carlo simulation. From this simulation, we calculated point estimates for each indicator, differences between salbutamol administration modes, and 95% confidence intervals. The models of the evaluated systems are available here.¹²

Results

Life cycle inventories

The life cycle inventories of salbutamol treatments using MDIs and nebulisation are reported in Table 1. The HFA used in the inhaler is 1,1,1,2-tetrafluoroethane, a gas having a global warming potential 1500 times that of CO₂.

The distances of the production plant and the incinerator (for both salbutamol administration methods) from the CHU were respectively 1605 and 1813 km.

Impact categories

The environmental footprint of the two methods is reported per impact category for one and three administrations in Tables 2 and 3. Specifically, for the climate change indicator, one and three ED-administered salbutamol treatments emit 1.9 and 4.0 kg of CO₂eq via MDI, compared with 0.9 and 1.0 kg via nebulisation. These emissions correspond to driving 5.5 km and 11.6 km, or 2.7 km and 2.8 km in a compact car (e.g. Honda Civic,

Toyota Corolla). e-Figures 2–5, presented in the supplementary material, provide a detailed breakdown of the contributions of each life-cycle stage to the different indicators for both MDI and nebulisation treatments.

The climate change hotspot for MDIs is HFA emissions, which account for 56% and 79% of the total CO₂-equivalent emissions for one and three administrations, respectively. In contrast, inhaler and spacer production contribute 33% and 16% of the total CO₂-equivalent emissions for one and three administrations, respectively. Their carbon footprint of MDIs is thus linked to their use: each series of eight inhalations emits 1.1 kg of CO₂eq as 1,1,1,2-tetrafluoroethane. These emissions are also a notable contributor to the other indicators (especially in the case of three series) but MDI and spacer production and disposal (of the plastic spacer more than the cardboard) are also important contributors. The results also indicate that although the single-use cardboard spacer leaves a smaller footprint than the plastic spacer after one administration, this difference diminishes or reverses in favour of the plastic spacer after three administrations, since the same cardboard can hardly be reused for more than one administration.

For nebulisation, cup and mask production and disposal are hotspots for all indicators. Cup and mask production accounts for 65% and 62% of the total CO₂-equivalent emissions for one and three administrations, respectively, while their end-of-life disposal contributes 33% and 31% of the total CO₂-equivalent emissions for one and three administrations, respectively. Since these devices are reusable, indicator results do not increase much with the number of administrations.

Because identical transport distances from the manufacturing plant to the user facility and from the facility to the incinerator were applied in modelling the life cycles of MDIs and nebulisation, transport does not influence the comparative assessment of their environmental footprints. In addition, the contribution of transport to the overall life cycles is marginal, accounting for only 1.9% and 3.3% of CO₂-equivalent emissions for MDIs and nebulisation, respectively.

Table 4 displays the median and 95% confidence interval of the difference between MDI and nebulisation for each impact category. The *Climate change* impact is significantly greater for MDI than for nebulisation, and this difference is greater for three administrations, reaching up to 2.9 kg CO₂eq. The two salbutamol treatment methods are indistinguishable in the *Human health* category for one and three administrations. Nebulisation has a greater negative impact on ecosystem quality after one administration, but the difference between the two methods is reversed after three administrations, as MDIs result in a greater loss of biodiversity. Nebulising shows significantly higher impact on *Fossil resources use* than MDI at both one and three administrations.

Table 1. Life cycle inventories of salbutamol administration in emergency departments using metered-dose inhalers and nebulization.

Component	Mass (g)	NMR/FT-IR Spectroscopy	EcolInvent 3.9 flow
Metered-dose inhaler			
<i>Chemical ingredients</i>			
Active substance	0.02	Salbutamol sulfate	Salbutamol sulfate
Norflurane propellant	17.3	1,1,1,2-Tetrafluoroethane	Refrigerant R134a
Surfactant	0.11	Water	Water, ultrapure
<i>Metering valve</i>			
Ferrule	1.1	Aluminium	Aluminium, primary, ingot
Gasket	0.13	N/A	N/A
Compression spring	0.09	Steel	Steel, unalloyed
Tank seal	0.13	N/A	N/A
Stem	0.41	Polyoxyethylene	
Diaphragm	0.39	Polyoxyethylene	
Bottle emptier	0.76	Polyoxyethylene	
<i>Actuator</i>			
Actuator stem	8.62	Polypropylene	Polypropylene, granulate
Actuator safety cap	1.2	Polypropylene	Polypropylene, granulate
<i>Canister</i>			
Metal container	7.64	95% Aluminium et 5% Magnesium	Aluminum alloy, AlMg3
<i>Packaging</i>			
Drug label	0.14	Cellulose acetate	Printed paper, offset
Drug information leaflet	5.54	Cellulose acetate	Printed paper, offset
Primary packaging	5.15	Cellulose acetate*	Solid bleached and unbleached board carton
Shipping container	2.39	Cellulose acetate	Corrugated board box
Safety tape	0.01	Cellulose acetate with dye	Paper, melamine impregnated
Safety seals	0.02	Polypropylene	Polypropylene, granulate
Coded safety seal	0.004	Polyvinylchloride	Polyvinylchloride, bulk polymerized
<i>Plastic spacer</i>			
Mouthpiece	12.41	Polyester resin	Maleic unsaturated polyester resin
Internal valve	2.99	Silicon rubber	Silicone / poly dimethyl siloxane
Internal membrane	1.56	Polypropylene	Polypropylene, granulate
External air valve	1.64	Polyester resin	Maleic unsaturated polyester resin

(continued)

Table 1. Continued.

Component	Mass (g)	NMR/FT-IR Spectroscopy	EcoInvent 3.9 flow
Opaque side	11.25	Polypropylene	Polypropylene, granulate
Transparent side	15.42	Polypropylene	Polypropylene, granulate
Mouthpiece cap	3.16	Polypropylene	Polypropylene, granulate
Packaging	2.8	Polyethylene	Polyethylene, high density, granulate
Cardboard spacer			
Internal part	12.77	Paper	Containerboard, unspecified
External part	24.06	Polyvinyl chloride carbonylated 2%	Polyvinylchloride, bulk Polymerised
Plastic film	0.21	Polypropylene	Polypropylene, granulate
Packaging	2.06	Polyethylene	Packaging film, low density Polyethylene
User instructions	9.03	Paper	Printed paper, offset
Nebulization			
Chemical ingredients			
Active substance	0.05	Salbutamol sulfate	salbutamol sulfate
Surfactant 1	0.01	Water	water, ultrapure
Surfactant 2	0.05	Sulfuric acid	sulfuric acid
Surfactant 3	0.002	Benzalkonium Chloride	benzalkonium Chloride
Container			
Vial	38.5	Glass	packaging glass, brown
Cap	1.75	Polypropylene	polypropylene, granulate
Packaging			
Drug Label	0.26	Polypropylene	polypropylene, granulate
Drug information leaflet	2.15	Cellulose acetate	printed paper, offset
Primary packaging	3.34	Cellulose acetate	containerboard, unspecified
Safety tape	0.79	Polyethylene	packaging film, low density polyethylene
Saline tube			
Plastic tube	2.27	Polyethylene	polyethylene terephthalate, granulate, bottle grade
Water	3.00	N/A	Water, ultrapure
Sodium salt	0.03	N/A	sodium chloride, powder
Nebulizing cup			
Plastic packaging	1.14	Polyethylene	packaging film, low density polyethylene
Information leaflet	1.11	Paper	printed paper, offset

(continued)

Table 1. Continued.

Component	Mass (g)	NMR/FT-IR Spectroscopy	EcolInvent 3.9 flow
cap	6.68	Polypropylene	polypropylene, granulate
Drug mixing chamber	7.02	Polystyrene (+/- chlore)	polystyrene, general purpose
Internal component of the reservoir	1.68	Polystyrene (+/- chlore)	polystyrene, general purpose
<i>Tubing</i>			
Plastic tube	41.36	Polyester, isophthalic acid (Vinyl)	isophthalic acid based unsaturated polyester resin
Packaging	1.80	Polyethylene	Polyethylene, high density, granulate
Information leaflet	1.12	Paper	Printed paper, offset
<i>Adult Oxygen Mask</i>			
Packaging	2.96	Polyethylene	packaging film, low density polyethylene
Information leaflet	0.29	Paper	printed paper, offset
Tube connector	2.24	Polypropylene	polypropylene, granulate
Mouthpiece	24.54	Poly butylene Terephthalate	polybutylene terephthalate_model
Metal hook	0.55	Aluminum	aluminium, primary, ingot
safety rubber	1.20	Polyamide	nylon 6-6
Tubing	40.78	Polyester (polybutylene terephthalate)	polybutylene terephthalate_model

Table 2. Climate change and human health indicators for salbutamol administration in the emergency department.

# admin	Mode of administration	Climate change (kg CO ₂ eq)		Human health (DALY)	
		Point estimate ^a	Median (IQR) ^b	Point estimate × 10 ⁻⁶	Median (IQR) × 10 ⁻⁶
1	MDI/plastic spacer	1.89	1.91 (1.80; 2.05)	4.1	1.7 (−64.3; 70.0)
	MDI/cardboard spacer	1.66	1.70 (1.58; 1.83)	3.3	2.1 (−97.8; 99.3)
	Nebulization	0.95	1.10 (1.06; 1.14)	3.9	13.0 (−191.2; 185.5)
3	MDI/plastic spacer	4.00	4.05 (3.69; 4.43)	6.0	5.8 (−55.6; 74.9)
	MDI/cardboard spacer	3.96	4.00 (3.66; 4.38)	6.0	5.7 (−182.0; 193.7)
	Nebulization	0.99	1.13 (1.10; 1.18)	4.0	2.7 (−186.0; 206.1)

^aPoint estimates obtained from impact evaluation of the life cycle assessment methodology.

^bMedians and interquartile ranges (IQR) estimated using a Monte Carlo simulation (1000 iterations).

#admin: number of administrations in the emergency department.

MDI: metered-dose inhaler; CO₂eq: CO₂ equivalent emissions; DALY: disability-adjusted life-year.

MDI left to the patient for home use

The environmental footprint of the scenario in which the patient upon discharge is allowed to keep the MDI for use at home is reported in e-Table 1. For all categories, the impact of this scenario is lower than disposal of the

MDI at the hospital. While the contribution of HFA emission continues to increase, the contribution of MDI production and disposal is spread over 200 inhalations instead of eight or 24 (one or three administrations) per functional unit. The previously observed differences between MDIs and nebulisation for all indicators do not

Table 3. Biodiversity and fossil resource use indicators for salbutamol administration in the emergency department.

# admin	Mode of administration	Ecosystem quality (PDF-m ² -year)		Fossil resources (Megajoules deprived)	
		Point estimate ^a	Median (IQR) ^b	Point estimate	Median (IQR)
1	MDI/plastic spacer	0.95	0.96 (0.70; 1.28)	9.44	9.75 (9.49; 10.04)
	MDI/ cardboard spacer	0.76	0.78 (0.50; 1.09)	5.93	6.20 (5.98; 6.39)
	Nebulization	0.97	1.12 (0.33; 1.94)	14.00	16.77 (16.08; 17.53)
3	MDI/plastic spacer	1.36	1.42 (1.12; 1.68)	9.44	9.73 (9.46; 10.00)
	MDI/ cardboard spacer	1.41	1.47 (0.95; 1.99)	8.64	9.02 (8.72; 9.31)
	Nebulization	1.01	1.25 (0.36; 2.10)	14.60	17.38 (16.63; 18.13)

^aPoint estimates obtained from impact evaluation of the life cycle assessment methodology.
^bMedians and interquartile ranges (IQR) estimated using a Monte Carlo simulation (1 000 iterations).
#admin: number of administrations in the emergency department.
MDI: metered-dose inhaler; PDF-m²-year: Potentially disappeared fraction of species over square meter years.

change significantly under this scenario. We estimated a difference of 2.5–2.6 kg CO₂eq between MDI and nebulisation for three treatments, with no significant differences noted in other categories of impact.

One-year ecological footprint

In fiscal year 2022–2023, 4815 MDIs and 233 nebuliser ampoules were dispensed in the five EDs associated with the CHU. The corresponding annual environmental footprint is reported by impact category in Table 5, based on each patient receiving three administrations of salbutamol while in the ED. An emission of 19,260 kg of CO₂ equivalent is attributable to the use of MDIs. If all patients had received nebulisation, this emission would have been 14,416 kg lower, and losses of 0.93×10^{-2} DALY and 1606 PDF-m²-year would have been avoided, but an additional 25,984 MJ in fossil resources would have been consumed. The 14,416 kg of CO₂eq emissions is equivalent to driving 84,800 km in a compact car (e.g. Honda Civic, Toyota Corolla) or 19 trips from New York to Los Angeles.

Discussion

Statement of principal findings

In this product/process life cycle assessment, we examined ED treatment of acute asthma using salbutamol administration via MDIs versus nebulisation. Nebulisation was found to have half the carbon footprint of one MDI administration and one quarter of three MDI administrations. The two methods are indistinguishable in the *Human health* category for one and three administrations, and in the *Ecosystem quality* category for one administration but

not three, at which the MDI had a significantly higher impact. Nebulising shows significantly higher impact on *Fossil resources use* for one or three MDI administrations. When scaled to the 5000 patients treated annually for asthma in the EDs of the institution where this research was conducted, nearly 20,000 kg CO₂ equivalent emissions would be attributable to the use of MDIs and nearly 15,000 kg would be avoided by prescribing nebulisation.

Strengths and weaknesses of the study

This study has several noteworthy strengths. First, to our knowledge, it is the first to compare the ecological footprint of MDIs and nebulisation, the two main methods of bronchodilator administration in EDs and hospital settings. In addition, it rigorously followed ISO 14040 and ISO 14044 standards governing life cycle assessment methodology. Notably, it includes a Monte Carlo simulation (1000 iterations) to account for data uncertainty and generate confidence intervals that strengthen the robustness of the comparison. Finally, it offers an extrapolation of the functional unit over a full year of activity in the participating EDs, allowing readers to better understand the potential ecological impact of their own therapeutic choices.

Among the limitations of this study, we must mention our creation of the life cycle inventories without access to industry information. However, the method used is scientifically robust and reproducible, and we are confident that the resulting analysis adequately estimates the differences in environmental footprint between MDI use and nebulisation. Our results might have differed if other inventory databases and impact assessment methods had been used. However, the ecoinvent database is one of the most widely used in the world, and

Table 4. Differences between administering salbutamol via metered-dose inhaler and nebulization in the emergency department: environmental indicators.

# admin	Modes	Climate change (kg CO ₂ eq)	Human health (DALY) × 10 ⁻⁵	Ecosystem quality (PDF·m ² ·year)	Fossil resources (MJ deprived)
1	MDI/plastic spacer minus Nebul	0.85 (0.84 to 0.86) ^a	0.84 (−0.31 to 1.99)	−0.12 (−0.17 to −0.07)	−6.99 (−7.06 to −6.92)
	MDI/cardboard spacer minus Nebul	0.61 (0.60 to 0.62)	−1.05 (−2.37 to 0.26)	−0.37 (−0.43 to −0.32)	−10.58 (−10.65 to −10.51)
3	MDI/plastic spacer minus Nebul	2.92 (2.89 to 2.96)	−0.93 (−2.10 to 0.25)	0.21 (0.15 to 0.26)	−7.68 (−7.75 to −7.61)
	MDI/cardboard spacer minus Nebul	2.91 (2.88 to 2.95)	−0.20 (−1.85 to 1.45)	0.30 (0.25 to 0.35)	−8.38 (−8.45 to −8.31)

^aDifference (95% Confidence Interval) between the treatment options estimated using a Monte Carlo simulation (1000 iterations).
 #admin: number of administrations.
 MDI: metered-dose inhaler; CO₂eq: CO₂ equivalent emissions; DALY: disability-adjusted life-year; Nebul: nebulization.
 PDF·m²·year: Potentially disappeared fraction of species over square meter years.

Table 5. Extrapolation of the ecological footprint of salbutamol administration via metered-dose inhaler and nebulization according to medication consumption recorded at the CHU de Québec-Université Laval in fiscal year 2022–23.

Administration mode	Number of patients	Climate change (kg CO ₂ eq)	Human health (DALY) × 10 ⁻²	Use of fossil resources (MJ)	Ecosystem quality (PDF·m ² ·year)
MDI/plastic spacer	4815 ^a	19,260	2.89	45,454	6548
Nebulization	78 ^b	77	0.03	1139	79
If only Nebulization had been used	4893	4844	1.96	71,438	4941
Potentially saved if only Nebulization used		14,416	0.93	−25,984	1606

^aRepresents the number of salbutamol metered-dose inhalers served in the emergency department in 2022–23.
^bRepresents the number of nebulization ampoules ($n = 233$, 5 mg/mL) consumed in the emergency department in 2022–23 divided by three assuming all patients received three treatments of 5 mg of salbutamol (15 mg in total).
 MDI: metered-dose inhaler; CO₂eq: CO₂ equivalent emissions; DALY: disability-adjusted life year; PDF·m²·year: Potentially Disappeared Fraction of species per square meter per year.

processes were adapted to the Québec context when this was relevant. The CO₂eq assessment method is that proposed by the Intergovernmental Panel on Climate Change, a widely recognised international organisation created under the auspices of the UN to assess risks related to climate change. We believe that this choice of tools makes our analysis as robust and credible as presently possible. Finally, to estimate the one-year environmental footprint, we assumed that patients received their three MDI treatments at 20-min intervals, since this is the protocolised prescription for asthma treatment in the CHU EDs. Since a significant number of patients end up receiving more than three treatments, our extrapolations are likely underestimates of the real impact.

Differences in results with previous studies

Goulet et al. compared HFA-based MDIs to a portable nebuliser device for use at home by patients with COPD.¹³ Comparisons with their study should be made carefully since: (1) a different functional unit was used (200 µg of Albuterol by MDI and 3 mg by nebuliser); (2) the nebuliser device studied is not used in the ED; and (3) MDI administration was modelled alone without a spacer. Still, the authors calculated a carbon footprint 2–3 times higher for one dose with an MDI compared to one dose with a nebuliser, whereas we estimated that one emergency treatment with an MDI has twice the carbon footprint of nebulisation. In absolute numbers,

their CO₂eq associated with MDI use appears disproportionately low (0.097 kg CO₂eq for two inhalations) compared to our estimates (1.89 kg CO₂eq for eight inhalations). However, the Goulet et al. model contained 6.7 g of HFA compared to 17.3 g used in our calculations. Their method of estimating the quantity of HFA is not described in detail, whereas our approach is reproducible and aligns with the quantities estimated another study that focused on gas kinetics associated with pressurised MDIs.¹⁴

We also modelled the scenario in which the patient uses the MDI at home, which was found to lead to a lower carbon footprint. However, dry powder inhalers (DPI), which can be used by patients aged 6 and above,¹⁵ have been found comparable in efficacy¹⁶ and cost¹⁷ to MDIs and to have a carbon footprint 20–30 times smaller.¹⁸ If DPIs are in fact usable at home in the same manner as bronchodilators, then discarding MDIs after use in the ED would become the approach having the least impact as a source of greenhouse gas emission.

Implications for clinicians and future research

This study of a specific aspect of the environmental footprint of healthcare systems suggests that nebulisation is a more eco-efficient method of administering bronchodilators in EDs that receive many patients needing such treatments. However, particularly in children, this method has been associated with more side effects and longer ED stays.⁸ Further research is needed to determine if the use of DPIs is effective and safe as ED treatment of mild to moderate acute asthma, which would allow nebulisation to be reserved for the most severe cases.

Conclusion

Acute asthma is one of the most frequent conditions treated in EDs. The administration of salbutamol for this purpose usually involves the use of an MDI, which has a significant environmental footprint. Our study shows that administering salbutamol by nebulisation has a smaller footprint. Given that more and more governments around the world are committed to providing healthcare services with net-zero greenhouse gas emissions over the coming decades, implementing low-emission ED treatment protocols for acute asthma should be one of many avenues to explore to achieve this goal.

Abbreviations

ED	emergency department
CO ₂ eq	CO ₂ equivalents
MDI	metered-dose inhalers
COPD	chronic obstructive pulmonary disease
HFA	hydrofluoroalkane
DALY	disability-adjusted life-year

MJ	megajoule
PDF·m ² ·year	potentially disappeared fraction of species over square meter years
IPCC2021	Intergovernmental Panel on Climate Change for 2021 – Global Warming Potential for 100-year period
GWP100	
DPI	dry powder inhaler

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Data availability: All life cycle assessment models are freely available on the Université Laval research data repository.¹²

Author contributions: SB and JRG designed the study. SB and AB supervised its conduct. AB, TM, CS and SB collected the inventory data. SB and JFM carried out the life cycle assessment. SB drafted the initial manuscript. All authors proofread the manuscript and approved its submitted version. SB assumes responsibility for the integrity of the data used in this study and the accuracy of its analysis.

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