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Sustainable Inhalers in Asthma and COPD: Balancing Environmental Impact and Patient Patient-Centered Care

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Abstract

Background: Inhaled pharmacotherapy is the cornerstone of management for asthma and chronic obstructive pulmonary disease (COPD), yet inhalers contribute measurably to the carbon footprint of healthcare delivery. This burden is attributable predominantly to pressurized metered-dose inhalers (pMDIs), which use hydrofluoroalkane propellants with a high global warming potential (GWP). Dry powder inhalers (DPIs) and soft-mist inhalers (SMIs) are propellant-free, and pMDIs formulated with low-GWP propellants are under development.

Objective: To review the evolution of inhaler technologies from conventional pMDIs to DPIs, SMIs and low-GWP pMDIs, and to appraise strategies for reducing environmental impact without compromising clinical effectiveness or patient-centred care.

Methods: A narrative review was undertaken using PubMed, Scopus and Google Scholar for articles published between [2019 and 2026]. Search terms encompassed inhaler carbon footprint, propellants, device classes, inspiratory flow, inhaler technique and sustainable prescribing. Reviews, clinical studies, life-cycle assessments and guidelines were synthesized qualitatively.

Results: Transition from high-GWP pMDIs to propellant-free or low-GWP devices has considerable potential to reduce greenhouse gas emissions. However, device suitability depends on patient-specific factors, including inspiratory flow, hand-breath coordination, dexterity, cognitive function, preference and disease severity, and handling errors occur across all device classes. Switching without clinical assessment may impair disease control, and exacerbations carry attendant clinical and environmental costs. Low-GWP pMDIs may offer a lower-carbon option for patients best served by pressurized devices, although regulatory approval and real-world effectiveness data remain limited.

Conclusions: Environmental impact should be incorporated as one criterion in inhaler selection, alongside efficacy, correct use and patient preference. A stepwise approach is proposed: optimization of disease control and inhaler technique, followed by selection of the lowest-carbon device that the patient can use reliably.

Keywords: asthma; COPD; inhalers; pressurized metered-dose inhaler; dry powder inhaler; soft-mist inhaler; low-GWP propellants; carbon footprint; sustainable prescribing; patient-centred care

1. Introduction

Asthma and chronic obstructive pulmonary disease (COPD) are among the most prevalent chronic respiratory diseases worldwide and account for a substantial burden of morbidity, mortality and health-system expenditure [1,2]. Inhaled therapy is the mainstay of treatment in both conditions, because it delivers drug directly to the airways and limits systemic exposure, and current international strategy documents place inhaled bronchodilators and corticosteroids at the centre of long-term management [1,2]. As a result, inhalers are among the most frequently prescribed medicines globally. Their effectiveness, however, depends not only on the pharmacological agent but also on the delivery device and on the patient's ability to use it correctly; critical handling errors are common across device types and are associated with poorer clinical outcomes [3].

In parallel with this clinical focus, the environmental footprint of healthcare has attracted increasing scrutiny, and inhaled therapy has emerged as an identifiable contributor. The carbon footprint of a pressurized metered-dose inhaler (pMDI) arises predominantly from the hydrofluorocarbon (HFC) propellants it contains, principally HFC-134a and HFC-227ea, both potent greenhouse gases that are released with every actuation [4,5]. The propellant has been estimated to account for approximately 96% of the global warming potential (GWP) of a pMDI, whereas the active ingredient contributes little [5]. Reported 100-year GWP values are of the order of 1,300-1,430 for HFC-134a and over 3,000 for HFC-227ea relative to carbon dioxide, with exact figures depending on the assessment report used [5]. Several analyses have quantified the consequences of device choice. Using carbon footprint estimates of approximately 20 kg CO2-equivalent per pMDI and 1 kg CO2-equivalent per DPI, Janson and colleagues calculated annual footprints of about 440 kg CO2-equivalent per patient for pMDI-based

treatment versus 17 kg for comparable DPI-based treatment, and noted that pMDIs represented around 70% of inhalers used for asthma and COPD in the United Kingdom in 2017 compared with 13% in Sweden [6]. An economic and carbon footprint analysis of NHS prescribing data in England estimated that replacing 10% of pMDIs with equivalent DPIs would avoid roughly 69 kilotonnes of CO2-equivalent annually [5,7]. Importantly, footprints vary considerably between pMDI products, reflecting differences in propellant type and fill volume, so that not all pMDIs are equivalent from an environmental standpoint [7]. More recent product-level analyses likewise report that pMDIs have a carbon footprint typically 20- to 40-fold higher than that of DPIs and SMIs [8].

The current position reflects a long technological evolution. Early metered-dose inhalers relied on chlorofluorocarbon (CFC) propellants, which were phased out because of their ozone-depleting properties and replaced by HFCs [6]. HFCs are not ozone-depleting but are themselves greenhouse gases, and they are now subject to phase-down under the Kigali Amendment to the Montreal Protocol [9]. This regulatory trajectory, together with national net-zero commitments in healthcare, has accelerated interest in three complementary strategies: increased use of propellant-free devices such as DPIs and SMIs where clinically appropriate; reduction of avoidable inhaler use through better disease control; and reformulation of pMDIs with next-generation, low-GWP propellants such as HFA-152a and HFO-1234ze(E) [4,5].

The third strategy is particularly relevant because it may allow the familiar pMDI format to be retained. A cradle-to-grave life-cycle assessment of a triple-therapy pMDI reported that replacing HFA-134a with HFO-1234ze(E) would reduce the propellant's GWP by more than 99% and the greenhouse gas emissions of the whole device by at least 85%, bringing the per-dose footprint to a level typical of a DPI [10]. The same analysis anticipated that transition across a manufacturer's portfolio and markets would take at least five years after the first product launch, indicating that low-GWP pMDIs will not be widely available in the short term [10].

Nevertheless, the device with the lowest carbon footprint is not necessarily the most suitable device for an individual patient. Effective use of many DPIs requires sufficient inspiratory flow to overcome internal device resistance, which may not be achievable in some patients with severe COPD, in older adults or during exacerbations; pMDIs require hand-breath coordination unless used with a spacer; and patient preference and previous experience influence adherence [3,5,8]. Inappropriate switching may therefore compromise disease control, and poor control carries its own environmental cost through additional reliever use, exacerbations, urgent care and hospital admission [11]. Recent position statements from respiratory professional bodies have accordingly emphasized that inhaler choice should balance personalized care with environmental responsibility rather than be driven by carbon footprint alone [12,13].

In this context, the present narrative review describes the evolution of inhaler technologies from conventional pMDIs to DPIs, SMIs and low-GWP pMDIs. It examines the patient-related and clinical factors that determine device suitability and proposes a pragmatic, stepwise framework for sustainable and individualized inhaler selection in asthma and COPD.

2. Methods

This narrative review was designed to synthesize the evidence on inhaler sustainability and device selection rather than to answer a single quantitative question. PubMed, Scopus and Google Scholar were searched for English-language articles published between [2019 and 2026], with the reference lists of key papers screened manually. Search terms combined "asthma" or "COPD" with "carbon footprint", "global warming potential", "pressurized metered-dose inhaler", "dry powder inhaler", "soft-mist inhaler", "low-GWP propellant", "HFO-1234ze", "HFA-152a", "peak inspiratory flow", "inhaler technique" and "sustainable prescribing".

Reviews, observational and interventional studies, life-cycle assessments, economic analyses, position statements and clinical guidelines were eligible. Articles were selected for relevance by the authors, and no formal risk-of-bias assessment was performed, which is consistent with the narrative design. Where industry data or conference abstracts were used, particularly for emerging propellants, this is stated explicitly. Findings are presented thematically: device technologies and their environmental impact, low-GWP propellants, patient and clinical determinants of suitability, and a practical framework for device selection.

3. Pressurized Metered-Dose Inhalers: Technology, Propellants and Environmental Impact

The pressurized metered-dose inhaler was introduced in the 1950s and remains one of the most widely used delivery systems. A pMDI contains drug dissolved or suspended in a liquefied propellant within a pressurized canister, and each actuation through a metering valve releases a fixed dose as an aerosol. Its principal advantages are portability, low cost, a compact multi-dose format, a rapid onset of delivery and relatively low demands on inspiratory effort; when used with a valved holding chamber (spacer), the need for hand-breath coordination is reduced and oropharyngeal deposition falls [3,5,14]. These properties explain why pMDIs remain the default reliever device in many health systems and are often the only affordable option in resource-limited settings [5].

The propellants used in pMDIs have changed over time for environmental reasons. Chlorofluorocarbons were used until the early 1990s and were then replaced by hydrofluoroalkanes (HFAs) because of their ozone-depleting effect [6]. HFA-134a and HFA-227ea do not damage the ozone layer, but they are strong greenhouse gases and are released into the atmosphere with every actuation, including the actuations remaining in discarded canisters [4,5]. Because the propellant accounts for the large majority of a pMDI's life-cycle emissions, device choice, rather than drug choice, largely determines the carbon footprint of inhaled therapy [5,6].

The carbon footprint varies substantially between pMDIs. In the English prescribing analysis, some salbutamol reliever products carried more than 25 kg CO2-equivalent per inhaler, whereas others using a smaller propellant volume had less than 10 kg, and HFA-227ea combination inhalers exceeded 36 kg compared with under 20 kg for equivalent HFA-134a products [7]. Consequently, "switching from pMDI" is not the only lever: choosing a small-volume HFA-134a product over a large-volume or HFA-227ea product can also yield meaningful savings for patients who need to remain on a pMDI [7]. At population level, reliever overuse is a further driver, because short-acting beta-agonist canisters are the most emission-intensive items in asthma care and poor control increases their use [11].

Table 1 summarizes the main technical and environmental characteristics of the principal device classes discussed in this review.

Table 1. Comparison of inhaler device classes

Feature	Conventional pMDI	Low-GWP pMDI (in development)	DPI	Soft-mist inhaler
Propellant	HFA-134a or HFA-227ea	HFA-152a or HFO-1234ze(E)	None	None (mechanical energy)
Carbon footprint per dose	Highest	Projected to approach DPI levels [10]	Low	Low
Inspiratory effort	Low to moderate	Low to moderate	Moderate to high, device-dependent	Low
Coordination needed	High; reduced with spacer	High; reduced with spacer	Low	Moderate
Spacer use	Yes	Likely, product-specific	No	Not typical
Main limitation	Greenhouse-gas propellant	Availability, regulation, limited real-world data	Unsuitable if inspiratory flow is inadequate; moisture sensitivity	Narrow drug range; cost

General trends only; individual devices differ. Sources: [3,5,6,8,10].

4. Dry Powder Inhalers and Soft-Mist Inhalers

Dry powder inhalers deliver drug as a powder that is dispersed by the patient's own inspiratory effort. They are breath-actuated, which removes the need for hand-breath coordination, and they contain no liquefied propellant. Designs include capsule-based, pre-metered blister-based and reservoir devices, and these differ in internal resistance and in the inspiratory flow required to disaggregate the powder into particles that can reach the lower airways [14,15]. The environmental advantage is considerable:

using assumed footprints of about 1 kg CO2-equivalent per DPI and 20 kg per pMDI, one analysis estimated annual emissions of roughly 17 kg for DPI-based treatment compared with 440 kg for pMDI-based treatment [6]. Modelling suggests that replacing 10% of pMDIs with DPIs in the United Kingdom would avoid about 69 kilotonnes of CO2-equivalent each year [5,7].

The clinical question is whether this benefit can be obtained without loss of control. A post-hoc analysis of a pragmatic study in asthma reported that switching from a pMDI to a DPI lowered the carbon footprint while asthma control was maintained [16]. A narrative synthesis across environmental, clinical, cost and preference domains likewise concluded that DPIs should be considered first-line where clinically appropriate [5]. These findings should not be generalized beyond the populations studied: most data are from high-income settings, and trial participants are often better able to use DPIs than frail or older patients with severe COPD.

DPIs also have practical limitations. Effective use requires sufficient peak inspiratory flow to overcome device resistance, a requirement that may not be met in a proportion of patients with severe airflow obstruction, during exacerbations, in older adults and in young children [5,8,15]. Powder formulations are sensitive to humidity and to exhalation into the device, and the loss of the "spray" sensation can reduce confidence in dose delivery. Inhaler-specific errors, such as failing to load the dose or not inhaling forcefully, are frequent and are associated with worse outcomes [3,15,17]. Using several different DPI types in one patient adds to the risk of error, which is why a single device type for all of a patient's inhaled medicines is often preferred [14].

Soft-mist inhalers generate a slow-moving aerosol cloud through a mechanical, spring-driven mechanism and contain no propellant. The longer duration and lower velocity of the cloud reduce the dependence on rapid inspiratory effort and on precise coordination, and they have been associated with reduced oropharyngeal deposition [14]. Their carbon footprint per dose is low compared with pMDIs [8]. Their main limitations are the restricted range of available drugs, the need to prime and insert the cartridge, and cost. Although DPIs and SMIs contain more plastic and metal than a simple canister and generate more solid waste, life-cycle analyses indicate that the propellant emissions of conventional pMDIs outweigh these factors [8].

5. Low-GWP Propellants and Next-Generation pMDIs

For many patients, a pMDI, with or without a spacer, remains the most appropriate or the only practical device. The development of low-GWP propellants therefore addresses a gap that device switching cannot fill. Two candidate propellants dominate current development: HFA-152a, with a 100-year GWP roughly one-tenth that of HFA-134a, and HFO-1234ze(E), a hydrofluoroolefin with a GWP of approximately one or below, which degrades rapidly in the atmosphere [10]. Both are intended to be used in the same pMDI format, so that patients and clinicians retain a familiar device.

The most detailed published assessment comes from a cradle-to-grave life-cycle analysis of a budesonide/glycopyrronium/formoterol pMDI. Replacing HFA-134a with HFO-1234ze(E) reduced the GWP of the propellant by more than 99% and the greenhouse gas emissions of the whole device by at least 85%, yielding a per-dose footprint comparable to that of a DPI; other environmental impacts studied were also lower and the atmospheric transformation products were not considered of concern [10]. This analysis was reported as a conference abstract and was industry-sponsored, so independent peer-reviewed confirmation is needed.

Several challenges remain. Each new propellant requires reformulation and demonstration of equivalent dose delivery, particle size distribution, stability and safety; toxicological and, for HFA-152a, flammability considerations must be addressed in manufacturing and storage; and regulatory approval is required product by product. Manufacturers have estimated that transition across a portfolio and across markets will take at least five years after the first launch [10]. Evidence on real-world effectiveness, patient acceptability and cost is therefore limited, and the current regulatory status of individual products should be verified at the time of reading. Low-GWP pMDIs will help most in the short to medium term by lowering the footprint of patients who must remain on pressurized devices, but they do not remove the need for appropriate prescribing and disease control.

Supporting strategies complement propellant change. These include recycling and take-back schemes for used inhalers, which prevent residual propellant being released in landfill or incineration, correct disposal advice at the point of dispensing, and prescribing of the smallest propellant volume consistent with clinical need [5,7].

6. Patient and Clinical Factors in Device Selection

The best inhaler is the one that a patient can use correctly and consistently. Handling errors are common with every device class: systematic evidence links critical errors to poorer asthma and COPD outcomes, and error rates are not confined to older patients or to a single device type [3,17]. Assessment of technique is therefore a prerequisite for any device decision and should be repeated at review, as technique deteriorates over time without reinforcement.

Several patient characteristics influence suitability. Inspiratory capacity is the main determinant for DPIs; measurement of peak inspiratory flow against the resistance of the intended device, or at least a clinical judgment of inspiratory ability, is advisable in older patients, in those with severe COPD or recent exacerbation, and in children [5,8,15]. Dexterity, vision and cognition affect the ability to load a capsule, prime a cartridge or press a canister while inhaling; coordination difficulties favour DPIs, SMIs or pMDIs with a spacer. Patient preference matters because it predicts adherence: in a survey of patients, carbon footprint was rated as moderately important, but ease of use and cost were valued highly [4]. Using different device types for different inhalers raises the risk of mixed-up techniques, so a single device family for maintenance and reliever therapy is preferable when possible [14].

Clinical context also shapes the choice. Reliever use is the largest source of emissions from asthma care, and disease that is poorly controlled leads to more reliever use, more exacerbations and more urgent care [11]. Better control, through adherence, trigger management, appropriate maintenance therapy and biologics where indicated, is therefore an environmental measure as well as a clinical one. Position statements from respiratory bodies stress that inhaler decisions must remain personalized and that environmental benefit should not be pursued at the cost of control [12,13].

Health-system and equity considerations are important. In many low- and middle-income countries, generic pMDIs and spacers may be the only affordable and available option, and the cost of reliever pMDIs can be lower than that of DPI equivalents [5]. Policies that mandate switching without regard to cost, access and training risk widening inequalities. Evidence from such settings is scarce and should be a priority for research.

7. A Stepwise Framework for Sustainable Inhaler Selection

Because sustainability and suitability can pull in different directions, a structured process helps clinicians make consistent, defensible decisions. The framework below integrates the evidence discussed above and is intended to support, not replace, clinical judgment and local guidance.

1. **Optimize disease control first.** Confirm the diagnosis, review adherence, address triggers, and reduce over-reliance on short-acting relievers, because fewer exacerbations and fewer reliever canisters is the most reliable way to lower emissions [11].
2. **Assess the patient's ability.** Check technique, inspiratory flow, dexterity, cognition, age and prior experience, and ask about preference.
3. **Match the device class to ability.** Identify the devices the patient can use reliably: DPI if inspiratory flow is adequate, SMI or pMDI with spacer if flow or coordination is limited.
4. **Choose the lowest-carbon suitable option.** Among suitable devices, favour propellant-free devices or, if a pMDI is required, the smallest propellant volume or a low-GWP pMDI when available [7,10].
5. **Switch with shared decision-making.** Discuss the reasons for change, train the patient on the new device, avoid mixing several device types, and avoid switching during an exacerbation.
6. **Review early.** Reassess control, technique and satisfaction at a follow-up visit, and return to the previous device if control deteriorates.
7. **Close the loop.** Advise on recycling or take-back of used inhalers, and record the device decision in the patient's notes.

This sequence places control and correct use ahead of carbon footprint, which reflects the hierarchy of clinical priorities, yet it still allows environmental benefit to be pursued systematically in routine care.

8. Limitations and Future Directions

This narrative review had no registered protocol or formal quality appraisal, so selection bias is possible. Life-cycle methods differ between studies, most evidence comes from the UK and Europe, and low-GWP propellant data are largely from manufacturers. Future studies should test whether switching to DPIs, SMIs or low-GWP pMDIs preserves control and adherence, especially in COPD and in low- and middle-income settings, and standardized footprint labelling is needed.

9. Conclusion

Inhaled therapy is indispensable in asthma and COPD, and its environmental impact is substantial and largely avoidable. The propellants in conventional pMDIs are the dominant source of emissions, and propellant-free devices and, in future, low-GWP pMDIs offer a route to major reductions. However, no single device suits every patient, and the evidence supports a stepwise, individualized approach: optimize disease control and technique, match the device to the patient's abilities and preferences, and then select the lowest-carbon option that can be used reliably. Sustainability should be treated as an additional criterion within patient-centred care, not a substitute for it.

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