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Carbon Footprint of Inhaled Therapy in Routine Healthcare: A Six-Year Population- Based Study of Dispensing Data

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Research Article

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Abstract

Background

Healthcare decarbonisation requires reliable indicators capable of identifying the clinical practices and technologies responsible for greenhouse gas emissions. Inhaled therapies are particularly relevant because pressurised metered-dose inhalers contain propellants with a substantially greater climate impact than propellant-free devices. However, longitudinal evidence based on routine dispensing data remains limited. This study examined temporal changes in inhaler dispensing and associated carbon emissions between 2020 and 2025 and evaluated the potential of routinely collected pharmaceutical data to support population-level monitoring of sustainable respiratory care.

Methods

A retrospective, region-wide observational study was conducted using administrative dispensing data from a regional public healthcare system in north-western Spain. All inhalers dispensed through community pharmacies and reimbursed by the public healthcare system between 1 January 2020 and 31 December 2025 were included. Devices were classified as pressurised metered-dose inhalers (pMDIs), dry powder inhalers (DPIs), or soft mist inhalers (SMIs) and grouped by therapeutic class. Carbon emissions were estimated by multiplying the number of devices dispensed by product-specific emission factors expressed as kg CO_2e per inhaler. Annual dispensing patterns and estimated emissions were analysed descriptively by device type, therapeutic group, and calendar year.

Results

A total of 1,250,943 inhalers were dispensed during the six-year study period, generating an estimated cumulative carbon footprint of 9.27 million kg CO_2-equivalent. Although pMDIs represented 38.7% of dispensed devices, they accounted for 93.8% of total estimated emissions. Short-acting β_2-agonists were the largest therapeutic contributor, accounting for 46.5% of overall emissions. Annual dispensing volumes remained relatively stable, whereas estimated emissions increased from 1.45 million kg CO_2-equivalent in 2020 to a peak of 1.67 million kg in 2023, before declining to 1.52 million kg in 2025.

Conclusions

The environmental impact of inhaled therapy was determined primarily by inhaler technology and therapeutic composition rather than overall dispensing volume. Routine dispensing data may provide healthcare systems with a practical indicator for monitoring the environmental performance of respiratory care and identifying priorities for clinical review. When therapeutically appropriate, inhaler selection, optimisation of maintenance treatment, inhaler technique assessment, adherence support,

patient education, and shared decision-making may contribute to healthcare decarbonisation without compromising safe, effective, and person-centred respiratory care.

Implications for nursing management and practice

Routine dispensing data can help nursing managers and clinical teams identify inhaler technologies and therapeutic groups associated with the greatest environmental burden and incorporate measurable sustainability indicators into respiratory care governance. Nurses can translate these population-level findings into person-centred practice through inhaler technique assessment, adherence support, patient education, decision-making about clinically appropriate inhaler options. Integrating carbon literacy with pharmaceutical monitoring may support environmentally responsible respiratory care without compromising treatment effectiveness, patient safety, or individual preferences.

Introduction

Climate change represents a major public health challenge and an increasing threat to population health, health equity, and the sustainability of healthcare systems. At the same time, healthcare contributes approximately 4–5% of global greenhouse gas emissions, creating an ethical and operational imperative to reduce the environmental impact of care delivery [1, 2]. Environmental sustainability has consequently emerged as an additional dimension of healthcare quality that should be pursued without compromising clinical effectiveness, patient safety, or equitable access to treatment. Within this agenda, nurses occupy a pivotal position because of their involvement in patient education, treatment monitoring, resource use, clinical decision-making, and the day-to-day organisation of care [3, 4].

Pharmaceutical products represent an important source of healthcare-related emissions throughout their manufacturing, distribution, use, and disposal. Inhaled therapies are particularly relevant because they are widely used in the management of chronic respiratory diseases and differ markedly in their environmental impact. Pressurised metered-dose inhalers (pMDIs) contain hydrofluoroalkane propellants with high global warming potential, whereas dry powder inhalers (DPIs) and soft mist inhalers (SMIs) generally generate substantially lower emissions [5]. Consequently, the carbon footprint of respiratory treatment may depend more strongly on the inhaler technologies and therapeutic combinations used than on the overall volume of medication dispensed.

Reducing the environmental impact of inhaled therapy should not, however, be understood as the indiscriminate replacement of one device with another. Inhaler selection must remain guided by clinical indication, disease control, inspiratory capacity, manual dexterity, patient preference, adherence, and the ability to use the device correctly. International recommendations indicate that environmental impact may be considered when clinically appropriate and therapeutically equivalent alternatives are available [6, 7]. Environmental considerations should therefore complement, rather than replace, person-centred clinical decision-making.

Previous studies have shown that pMDIs contribute disproportionately to respiratory care emissions and that clinically appropriate changes in inhaler selection could produce meaningful carbon reductions [5, 8]. Particular attention has also been directed towards short-acting β_2-agonists (SABAs), as excessive reliance on rescue medication may indicate suboptimal disease control while simultaneously increasing the environmental burden of respiratory treatment [6]. Optimisation of maintenance therapy, appropriate device selection, correct inhaler technique, adherence support, and patient education may therefore contribute to both clinical quality and environmental sustainability.

Recent hospital-level evidence from Spain has highlighted the importance of measurable environmental indicators, feedback mechanisms, professional engagement, and structured monitoring within nurse-informed healthcare decarbonisation strategies [4]. However, evidence remains limited regarding how the carbon footprint of inhaled therapy evolves over time in routine healthcare practice. Many existing studies estimate emissions at a single point in time or model hypothetical switching scenarios [5, 8]. Fewer studies use longitudinal, population-level dispensing data to examine whether changes in device and therapeutic composition are accompanied by measurable changes in emissions while overall access to treatment is maintained. Routine pharmaceutical information systems may help address this gap by enabling healthcare organisations to monitor large-scale dispensing patterns, carbon intensity, and the contribution of specific technologies and therapeutic groups over time.

In Spain, healthcare sustainability is increasingly incorporated into national and regional initiatives aligned with the Paris Agreement and the European Green Deal [9, 10]. The Galician Circular Economy Strategy 2020–2030 provides a regional framework for advancing resource efficiency, circularity, and environmentally responsible healthcare [11]. Although changes in inhaler-related emissions cannot be attributed to a broad sustainability strategy in the absence of a defined intervention and appropriate comparator, population-level monitoring can determine whether dispensing patterns are evolving consistently with wider environmental objectives. Such monitoring may also identify priority areas for clinical review, professional education, organisational action, and future nursing-led or multidisciplinary interventions.

This study therefore aimed to examine temporal changes in inhaler dispensing and the associated carbon footprint within a regional public healthcare system between 2020 and 2025. Specifically, it assessed dispensing activity and estimated emissions by inhaler technology, therapeutic group, and calendar year, and evaluated whether routine dispensing data could provide a practical population-level indicator for monitoring the environmental performance of respiratory care.

Methods

Study design

A retrospective, region-wide observational study was conducted to describe temporal changes in inhaler dispensing patterns and estimate the associated carbon footprint between 1 January 2020 and 31

December 2025. The study used routinely collected, aggregated pharmaceutical dispensing data and was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [12].

The design was selected to evaluate inhaler-related environmental performance under routine healthcare conditions. The study did not evaluate a defined clinical or policy intervention and was therefore not intended to establish causal relationships between sustainability strategies and changes in dispensing or emissions.

Setting

The study was conducted within a regional public healthcare system in north-western Spain. The analysis covered inhalers dispensed through community pharmacies and reimbursed by the public healthcare system between 1 January 2020 and 31 December 2025. Privately purchased or otherwise non-reimbursed inhalers were not included.

Data source and unit of analysis

Dispensing data were obtained from the regional pharmaceutical information system and provided by the competent pharmaceutical services authority. Data extraction was performed by primary care pharmacists.The database contained routinely collected administrative records used for pharmaceutical reimbursement and prescribing management. Data were supplied in aggregated form and did not contain patient identifiers or individual-level clinical or sociodemographic information.

The unit of analysis was the pharmaceutical product presentation within each calendar year. The final dataset comprised 1,042 product-year dispensing records across the six-year study period. For each record, the available information included the pharmaceutical presentation, therapeutic composition, device type, number of packages dispensed, calendar year, and the emission factor assigned to the corresponding inhaler.

Identification and classification of inhaled therapies

Medicinal products were identified and classified according to the Anatomical Therapeutic Chemical (ATC) Classification System [13]. The analysis included products within group R03 (Drugs for obstructive airway diseases), specifically R03A (Adrenergics, inhalants) and R03B (Other drugs for obstructive airway diseases, inhalants).

Nebulised formulations were excluded because the study focused on handheld inhaler devices and the selected product-level emission-factor methodology did not permit directly comparable estimation of nebuliser-related emissions. Non-inhaled formulations and products outside the predefined ATC groups were also excluded.

Each product was classified by device technology as a pressurised metered-dose inhaler (pMDI), dry powder inhaler (DPI), or soft mist inhaler (SMI). Products were subsequently grouped according to therapeutic class: short-acting β_2-agonist (SABA), short-acting muscarinic antagonist (SAMA), inhaled corticosteroid (ICS), long-acting β_2-agonist (LABA), long-acting muscarinic antagonist (LAMA), ICS/LABA, LABA/LAMA, ICS/LABA/LAMA, or ICS/SABA.

Carbon footprint estimation

Product-specific carbon emission factors were obtained from the PrescQIPP inhaler carbon footprint resources [14]. When a directly matched product-specific factor was unavailable, device characteristics and propellant composition were verified using the official Summary of Product Characteristics available from the Spanish Agency of Medicines and Medical Devices online medicines database (Centro de Información online de Medicamentos de la AEMPS, CIMA) [15]. The product was then matched to the corresponding device- and propellant-specific emission factor following the PrescQIPP methodology.

Before analysis, emission factors were converted to a common unit of kilograms of carbon dioxide equivalent per complete inhaler device (kg CO_2e/device). For each product-year record, the number of inhalers dispensed was multiplied by the corresponding product-specific emission factor. The resulting estimates were then aggregated by calendar year, device technology, and therapeutic class to determine annual and cumulative emissions over the six-year study period.

To account for differences in dispensing volume, annual carbon intensity was calculated by dividing total estimated emissions by the total number of inhalers dispensed in the corresponding year. Expressed as kg CO_2e per inhaler, this indicator allowed changes in the technological and therapeutic composition of dispensing to be distinguished from changes associated with dispensing volume alone.

Data quality and calculation verification

Before analysis, product names, therapeutic classifications, device technologies, and emission-factor units were reviewed for internal consistency.All emission factors were converted to kg CO_2e per complete device before multiplication.

Arithmetic calculations were independently rechecked, and aggregated totals were reconciled across calendar year, device type, and therapeutic class. Records producing inconsistent subtotals or implausible emission values were returned to the product-level database for verification. Percentages were calculated using the corresponding reconciled total as the denominator.

Data analysis

Descriptive analyses were conducted to summarise dispensing activity and estimated carbon emissions by calendar year, device technology, and therapeutic class. Dispensing activity was reported as absolute

frequencies and percentages. Carbon emissions were expressed as kg CO_2e, and carbon intensity was reported as kg CO_2e per inhaler.

Absolute and relative changes in dispensing volume, estimated emissions, and carbon intensity were calculated across the complete study period and between the year with the highest estimated emissions and the final study year. Temporal patterns were examined descriptively because the available dataset contained annual aggregated observations and the study was not designed for causal inference or formal evaluation of an intervention. No patient-level statistical analyses were performed.

Results

Overall dispensing activity and carbon footprint

A total of 1,250,943 inhalers were dispensed between 2020 and 2025, generating an estimated cumulative carbon footprint of 9,274,830.06 kg CO_2e. Annual dispensing volumes ranged from 193,892 inhalers in 2021 to 215,253 in 2024.

The number of inhalers dispensed increased by 4.6% between 2020 and 2025, from 203,493 to 212,846 devices. Estimated emissions increased from 1,445,023.96 kg CO_2e in 2020 to a peak of 1,666,989.74 kg CO_2e in 2023. Emissions subsequently decreased to 1,523,432.56 kg CO_2e in 2025, representing an 8.6% reduction from the 2023 peak despite persistently high dispensing volumes.

Annual carbon intensity increased from 7.101 kg CO_2e per inhaler in 2020 to 7.765 kg CO_2e per inhaler in 2023 and subsequently declined to 7.157 kg CO_2e per inhaler in 2025. This represented a 7.8% reduction in carbon intensity between 2023 and 2025 (Table 1).

Table 1
Annual inhaler dispensing activity, estimated carbon footprint, and carbon intensity, 2020–2025

Year	Inhalers dispensed, n	Estimated carbon footprint, kg CO_2e	Carbon intensity, kg CO_2e/inhaler
2020	203,493	1,445,023.96	7.101
2021	193,892	1,447,826.60	7.467
2022	210,789	1,597,169.20	7.577
2023	214,670	1,666,989.74	7.765
2024	215,253	1,594,388.00	7.407
2025	212,846	1,523,432.56	7.157
Total	**1,250,943**	**9,274,830.06**	**7.414**

Note.*Carbon intensity was calculated by dividing the estimated annual carbon footprint by the corresponding number of inhalers dispensed. CO_2e, carbon dioxide equivalent.*

Dispensing and carbon footprint by inhaler technology

DPIs represented the largest proportion of dispensed inhalers, accounting for 695,602 devices (55.6%), followed by pMDIs with 483,766 devices (38.7%) and SMIs with 71,575 devices (5.7%).

The contribution of each technology to estimated emissions differed markedly from its contribution to dispensing volume. pMDIs generated approximately 8.70 million kg CO_2e and accounted for 93.8% of the cumulative carbon footprint despite representing fewer than 40% of all dispensed inhalers. DPIs generated approximately 527,165 kg CO_2e, corresponding to 5.7% of total emissions, whereas SMIs generated approximately 46,812 kg CO_2e, representing 0.5%.

The average estimated carbon intensity was therefore substantially greater for pMDIs than for propellant-free devices. Figure 1 summarises the distribution of dispensing activity and estimated emissions by inhaler technology, the principal therapeutic contributors, and the temporal pattern observed during the study period.

Dispensing and carbon footprint by therapeutic group

ICS/LABA combinations were the most frequently dispensed therapeutic group, accounting for 469,911 inhalers (37.6%), followed by SABA formulations with 257,197 inhalers (20.6%). However, SABA formulations generated the greatest environmental burden, producing an estimated 4,309,908.97 kg CO_2e and accounting for 46.5% of total emissions. ICS/LABA combinations generated an estimated 2,813,956.51 kg CO_2e, corresponding to 30.3% of the cumulative carbon footprint. Together, SABA and ICS/LABA therapies accounted for approximately 58% of dispensed inhalers and 77% of total estimated emissions.

In contrast, LABA/LAMA combinations accounted for 157,722 inhalers (12.6%) but generated only 1.1% of total emissions. Triple therapy with ICS/LABA/LAMA accounted for 84,747 inhalers (6.8%) and 3.4% of estimated emissions. These differences demonstrate that the environmental burden associated with each therapeutic group was strongly influenced by the device technologies through which treatment was delivered (Fig. 1).

Temporal changes in therapeutic composition

Dispensing of triple therapy increased from 4,676 inhalers in 2020 to 26,507 in 2025, corresponding to an absolute increase of 21,831 devices and a relative increase of 466.9%. This growth was not accompanied by a proportional increase in its contribution to total emissions because triple therapies were predominantly delivered through lower-carbon device technologies.

SABA dispensing also increased during the study period, from 37,816 inhalers in 2020 to 46,764 in 2025. Given the predominance of pMDIs within this therapeutic group, SABA formulations remained the largest therapeutic contributor to estimated carbon emissions.

Overall, the temporal pattern was characterised by relatively stable total dispensing, increasing estimated emissions until 2023, and a subsequent reduction in both total emissions and carbon intensity during 2024 and 2025. The aggregated data indicate that these changes were associated with differences in the technological and therapeutic composition of dispensed inhalers; however, the study design does not permit attribution to a specific clinical, organisational, or policy intervention.

Discussion

Main findings and interpretation

This six-year, region-wide study showed that the environmental impact of inhaled therapy was determined primarily by inhaler technology and therapeutic composition rather than by dispensing volume alone. A total of 1,250,943 inhalers were dispensed through the public healthcare system between 2020 and 2025, generating an estimated cumulative carbon footprint of 9.27 million kg CO_2e. Although pMDIs represented 38.7% of dispensed devices, they accounted for 93.8% of estimated emissions. SABA formulations were the largest therapeutic contributor, generating 46.5% of the total carbon footprint.

Annual dispensing volumes remained comparatively stable, whereas both estimated emissions and carbon intensity varied over time. Emissions reached their highest value in 2023 and subsequently declined by 8.6% between 2023 and 2025. Carbon intensity decreased by 7.8% over the same period, from 7.765 to 7.157 kg CO_2e per inhaler. These findings indicate that monitoring the number of inhalers dispensed alone is insufficient to assess the environmental performance of respiratory care. Changes in the mixture of device technologies and therapeutic groups must also be considered.

The study additionally identified contrasting temporal patterns across therapeutic groups. Triple therapy dispensing increased from 4,676 devices in 2020 to 26,507 in 2025 without a proportional increase in emissions, reflecting its frequent delivery through lower-carbon device technologies. Conversely, SABA dispensing increased from 37,816 to 46,764 devices and remained the largest therapeutic contributor to emissions because of the predominance of pMDIs within this group. These aggregated patterns identify potential priorities for clinical review but do not establish whether individual prescriptions were appropriate or whether disease control changed during the study period.

Comparison with previous evidence

The disproportionate contribution of pMDIs is consistent with previous evidence showing that hydrofluoroalkane propellants account for most greenhouse gas emissions associated with inhaled treatment [5]. DPIs and SMIs generally have substantially lower carbon footprints and may provide clinically effective alternatives for appropriately selected patients [5, 6]. The present study extends this evidence by demonstrating the same technological gradient across six consecutive years of routine dispensing within a regional public healthcare system.

Previous analyses have estimated that clinically appropriate changes in inhaler selection could achieve substantial carbon reductions [8]. However, lower emissions should not be pursued through indiscriminate device switching. International asthma and chronic obstructive pulmonary disease recommendations emphasise that inhaler selection must consider clinical indication, disease control, inspiratory capacity, manual dexterity, inhaler technique, adherence, and patient preference [6, 7]. The environmental impact of a device should therefore be incorporated as an additional consideration only when clinically appropriate and therapeutically equivalent options are available.

The large contribution of SABA formulations is clinically relevant because excessive reliance on rescue medication may indicate poor disease control, inadequate maintenance therapy, incorrect inhaler use, or other unmet treatment needs [6]. Nevertheless, dispensing data alone cannot distinguish excessive use from clinically justified treatment, identify the underlying respiratory diagnosis, or determine whether the dispensed medication was used. The present findings should therefore be interpreted as a population-level surveillance signal rather than evidence of inappropriate prescribing at the individual level.

The reduction in emissions and carbon intensity after 2023 occurred without a corresponding decline in overall dispensing. This pattern is compatible with changes in the technological or therapeutic composition of dispensed inhalers. However, the study did not evaluate a defined intervention and cannot identify the clinical, commercial, organisational, or policy mechanisms responsible for the observed change. Changes in product availability, prescribing preferences, therapeutic guidelines, device characteristics, or the introduction of lower-carbon formulations may all have contributed.

Implications for sustainable respiratory care and nursing practice

Reducing the environmental impact of inhaled therapy requires coordination between prescribers, nurses, pharmacists, respiratory specialists, healthcare managers, and patients. Routine dispensing data can identify technologies and therapeutic groups associated with the greatest environmental burden, but population-level monitoring must be translated into individualised clinical review before treatment decisions are made.

Nurses occupy a particularly important position at the interface between medication use, patient education, self-management, and healthcare organisation. In routine respiratory care, nurses assess inhaler technique, identify barriers to adherence, reinforce maintenance treatment, support symptom monitoring, and facilitate shared decision-making. These activities can help ensure that inhalers are used effectively and that unnecessary medication waste or repeated rescue medication use is identified. When clinically relevant alternatives exist, nurses can also support patients in understanding differences between devices, including their technique requirements and environmental implications.

The findings complement previous hospital-level evidence demonstrating the value of measurable environmental indicators, feedback systems, carbon literacy, and professional engagement within nurse-informed decarbonisation strategies [4]. While the earlier framework addressed institutional emission domains such as consumables, documentation processes, plastics, and anaesthetic gases, the present study introduces inhaler-related carbon intensity as a potential pharmaceutical indicator for sustainable clinical governance. Dispensing data could therefore be incorporated into periodic sustainability dashboards alongside conventional indicators of treatment quality and safety.

Environmental information should not create guilt, restrict access to effective treatment, or override patient preferences and clinical needs. For some patients, particularly those with limited inspiratory capacity, impaired manual dexterity, cognitive difficulties, or an established ability to use a pMDI correctly, a pressurised device may remain the safest and most appropriate option. Sustainable respiratory care should consequently focus on treatment optimisation and shared decision-making rather than carbon reduction in isolation.

Practice-oriented framework

Figure 2 translates the population-level findings into a practice-oriented framework for sustainable respiratory care. The framework links routine environmental monitoring with five potential areas of multidisciplinary action: clinically appropriate device and treatment review, inhaler technique assessment, adherence support, patient education, and shared decision-making. These actions are intended to support both effective respiratory treatment and environmental sustainability.

The framework is conceptual and was not empirically evaluated in the present study. It should therefore be interpreted as an implementation-oriented synthesis of the study findings rather than as a validated causal or predictive model. Its value lies in illustrating how population-level pharmaceutical indicators may inform person-centred clinical practice while preserving patient safety, therapeutic effectiveness, and individual choice.

Organisational and policy relevance

The decline in estimated emissions after 2023 occurred during the implementation period of the Galician Circular Economy Strategy 2020–2030 [11]. However, the observed reduction cannot be attributed to this strategy because the study did not evaluate a specific policy intervention, include a comparison region, or control for concurrent changes in product availability and clinical practice.

The findings nevertheless demonstrate the potential value of routine pharmaceutical information systems for environmental monitoring. Healthcare organisations could use dispensing volume, estimated emissions, carbon intensity, pMDI share, and SABA-related emissions as complementary indicators. These measures could help identify priorities for audit, clinical education, medication review, procurement, and prospective quality-improvement initiatives.

Environmental indicators should be interpreted alongside clinical measures rather than used as independent performance targets. Reductions in carbon intensity would not represent an improvement if they were accompanied by poorer disease control, reduced adherence, inequitable treatment access, or inappropriate device selection. Future monitoring systems should therefore integrate environmental outcomes with indicators such as exacerbations, symptom control, inhaler technique, adherence, treatment satisfaction, and healthcare utilisation.

Strengths and limitations

This study has several strengths. It included all publicly reimbursed inhalers dispensed within the study setting over six consecutive years, providing a comprehensive overview of routine dispensing patterns Product-level linkage between dispensing records and emission factors enabled estimated emissions to be examined by device technology, therapeutic group, and calendar year. The inclusion of carbon intensity provided an additional indicator capable of distinguishing changes in technological and therapeutic composition from changes in dispensing volume alone.

Several limitations should also be acknowledged. First, the retrospective observational design precludes causal inference regarding the factors responsible for temporal changes in dispensing or estimated emissions. No defined intervention was evaluated, and no comparison region was included.

Second, dispensing records do not demonstrate that inhalers were used, used correctly, or clinically appropriate. The database contained no patient-level information on respiratory diagnosis, disease severity, symptom control, inspiratory capacity, adherence, exacerbations, healthcare utilisation, or treatment outcomes. Consequently, the study cannot determine whether higher SABA dispensing reflected poor disease control, clinically justified use, medication accumulation, or other factors.

Third, the analysis covered inhalers reimbursed by the regional public healthcare system and did not include privately purchased or otherwise non-reimbursed products. The findings should therefore be interpreted as health-system-level rather than complete population-level estimates.

Fourth, carbon footprints were estimated using published product- and device-specific emission factors rather than directly measured emissions [14]. Differences in factor provenance, methodological boundaries, manufacturing processes, distribution pathways, and end-of-life assumptions may introduce uncertainty. Factors derived in other healthcare or commercial contexts may not fully represent the complete Spanish supply chain. Product-specific factors were treated as constant within the study period unless an updated device or propellant classification was identified.

Fifth, annual aggregation provided only six temporal observations. The analysis was therefore descriptive and could not assess seasonality, monthly changes, or statistically model temporal trends. The COVID-19 pandemic may also have influenced healthcare access, respiratory diagnosis, prescribing, dispensing, and medication use during the initial study years.

Finally, the study was conducted within a single provincial public healthcare system. Differences in respiratory disease prevalence, prescribing practices, reimbursement systems, product availability, and healthcare organisation may limit direct generalisation to other settings.

Future research

Future studies should use monthly or quarterly dispensing data to evaluate temporal patterns with greater precision and should incorporate uncertainty or sensitivity analyses for alternative emission factors. Multiregional comparisons would help determine whether the patterns observed in this regional healthcare system are consistent across healthcare systems with different prescribing and reimbursement structures.

Prospective nursing-led and multidisciplinary interventions should evaluate inhaler technique, adherence, maintenance treatment optimisation, shared decision-making, and clinically appropriate device selection. These studies should assess environmental outcomes alongside disease control, exacerbations, patient satisfaction, equity, and safety. Linking product-level environmental indicators with patient-level clinical outcomes would provide a stronger evidence base for determining whether sustainable respiratory care can simultaneously improve treatment quality and reduce carbon emissions.

Conclusions

This six-year study demonstrates that the environmental impact of inhaled therapy is determined primarily by inhaler technology and therapeutic composition rather than dispensing volume alone. pMDIs and SABA formulations accounted for disproportionate shares of estimated emissions, while both total emissions and carbon intensity declined after reaching their highest values in 2023.

Routine dispensing data may provide healthcare systems with a practical population-level indicator for monitoring the environmental performance of respiratory care and identifying priorities for clinical review. However, the observed changes cannot be attributed to a specific sustainability policy or clinical

intervention, and aggregated dispensing data do not establish treatment appropriateness, actual inhaler use, or patient-level outcomes.

Environmental considerations should therefore be integrated into respiratory care only when clinically appropriate and therapeutically equivalent options are available. Treatment optimisation, correct inhaler technique, adherence support, patient education, and shared decision-making may contribute to lower-carbon respiratory care while preserving treatment effectiveness, patient safety, equity, and individual preferences. Prospective multicentre research linking environmental indicators with clinical and patient-reported outcomes is required to determine the effectiveness and transferability of these approaches.

Relevance to clinical practice

The findings provide nursing and multidisciplinary respiratory teams with measurable information on the inhaler technologies and therapeutic groups responsible for the greatest environmental burden. At the individual level, nurses can use these population-level signals to inform inhaler technique assessment, adherence support, therapeutic education, identification of potentially excessive reliance on rescue medication, and shared decision-making about clinically appropriate device options.

At the organisational level, nursing managers may incorporate inhaler-related emissions, carbon intensity, pMDI share, and SABA dispensing into sustainability dashboards, clinical audits, and professional education. This approach extends previous nurse-informed decarbonisation work by connecting environmental monitoring with pharmaceutical management and person-centred respiratory care [3, 4]. It may help embed environmental sustainability within clinical governance without turning carbon reduction into an objective independent of treatment quality and safety.

Declarations

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Ethics approval and consent to participate

This study did not involve human participants, human biological material, identifiable personal data, individual prescriptions, or access to clinical records. It was based exclusively on aggregated, product-level administrative dispensing data provided by the Pharmaceutical Services Management Unit of the Regional Directorate of Pharmacy. Therefore, research ethics committee review and individual informed consent were not applicable. Authorisation for access to and use of the aggregated dispensing data was obtained from the competent pharmaceutical authority before the study commenced.

Competing interests

The authors declare that they have no competing interests.

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Figures

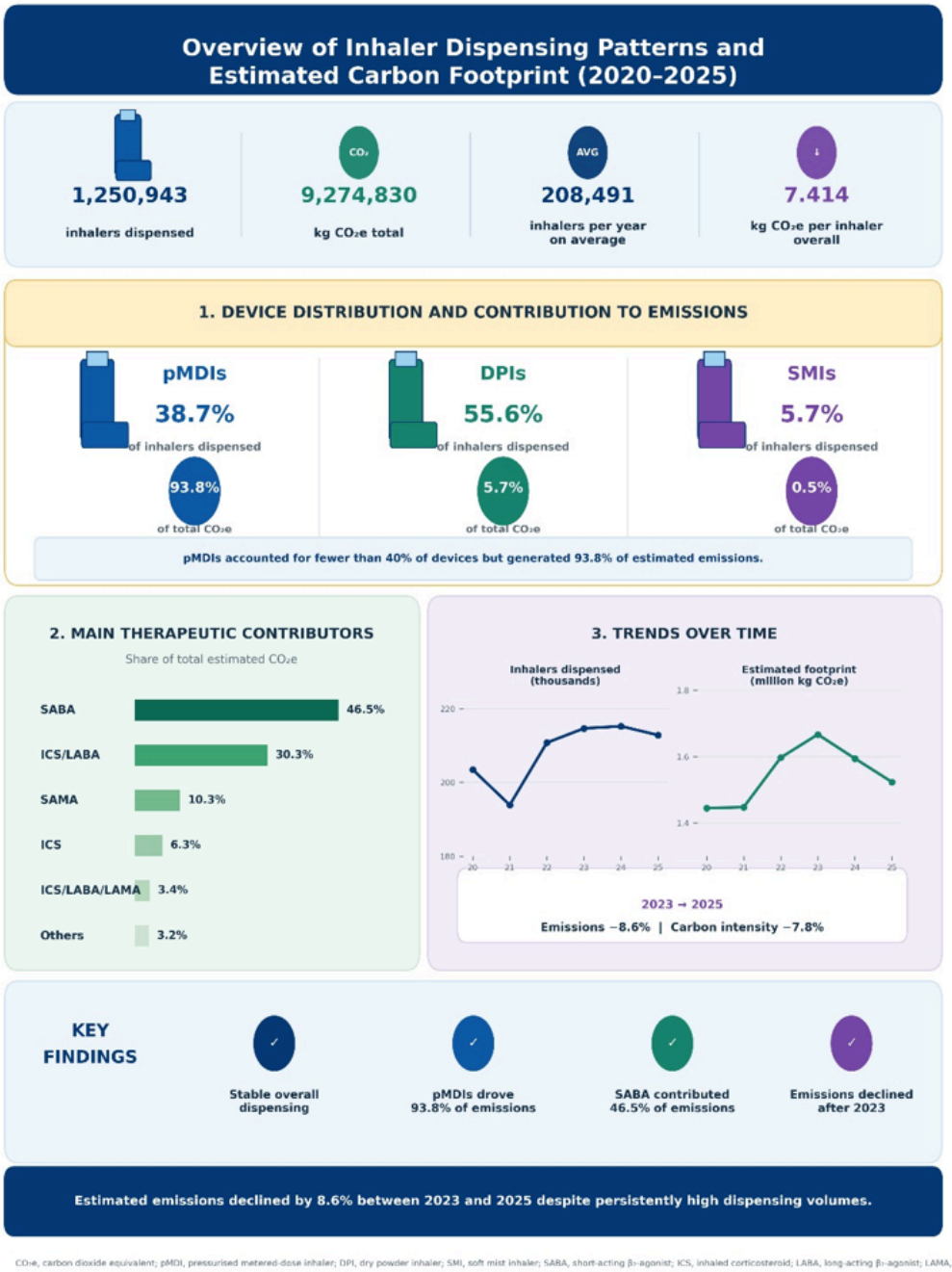


Figure 1

Overview of inhaler dispensing patterns and estimated carbon footprint, 2020–2025

Note. *CO_2e, carbon dioxide equivalent; DPI, dry powder inhaler; ICS, inhaled corticosteroid; LABA, long-acting β_2-agonist; LAMA, long-acting muscarinic antagonist; pMDI, pressurised metered-dose inhaler; SABA, short-acting β_2-agonist; SMI, soft mist inhaler.*

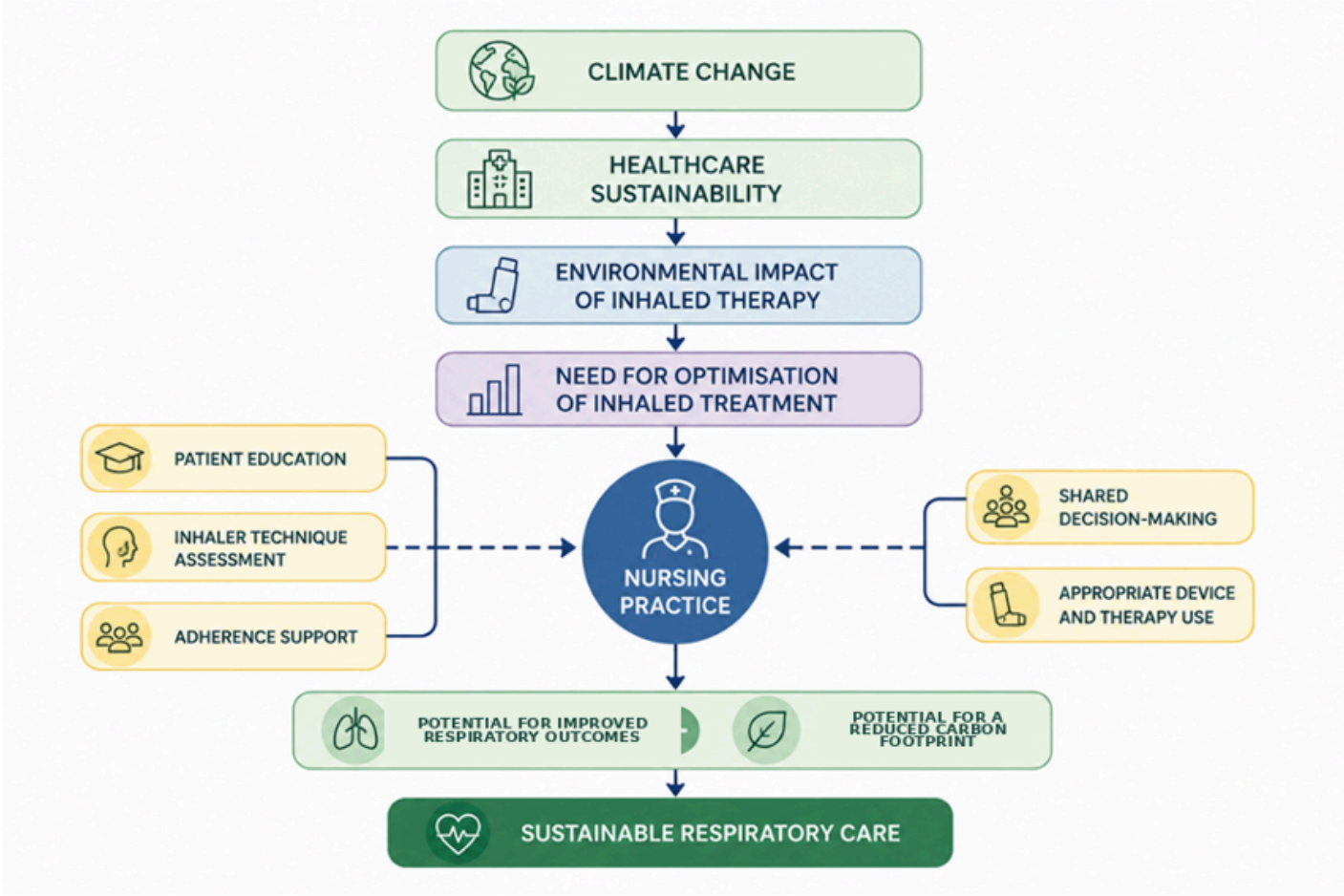


Figure 2

Practice-oriented framework for integrating environmental sustainability into respiratory care

Note. *The framework was developed to support interpretation and future implementation and was not empirically evaluated in this study.*