Environmental Sustainability in Respiratory Care: An Overview of the healthCARe-Based envirONmental Cost of Treatment (CARBON) Programme

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ABSTRACT

Introduction: Faced with the challenges of climate change, countries are seeking to decarbonise their economies. A greater understanding of what comprises the carbon footprint of care in healthcare systems will identify potential strategies for reduction of greenhouse gas (GHG) emissions. In respiratory care, the focus has been on preventer inhalers, thereby omitting contributions from other aspects such as healthcare resource utilisation (HCRU) and reliever inhaler use. The healthCARe-Based envirONmental cost of treatment (CARBON) programme aims to provide a broader understanding of the carbon footprint associated with respiratory care.

Methods: CARBON will quantify the carbon footprint of medications and HCRU among approximately 2.5 million patients with respiratory diseases from seven ongoing studies spanning more than 40 countries. Across studies, to obtain the carbon footprint of all inhaled, oral, and injectable medications, SimaPro life cycle assessment software modelling resource and energy consumption data, in addition to Ecoinvent® data sets and certified published studies, will be used. The carbon footprint of HCRU in the United Kingdom will be estimated by applying the methodology and data obtained from the Sustainable Healthcare Coalition Care Pathway Guidance.

Planned Outcomes: In asthma, CARBON studies will quantify GHG emissions associated with well-controlled versus not well-controlled asthma, the contribution of short-acting β2-agonist (SABA) reliever inhalers (and their potential overuse) to the carbon footprint of care, and how implementation of treatment guidelines can drive improved outcomes and footprint reduction. In chronic obstructive pulmonary disease (COPD), CARBON studies will assess the
impact of exacerbation history on GHG emissions associated with HCRU and SABA use in subsequent years and estimate the carbon footprint associated with all aspects of COPD care.

**Conclusion:** CARBON aims to show that the principle of evidence-led care focused on improvement of clinical outcomes has the potential to benefit patients and the environment.

**Keywords:** Asthma; Carbon footprint; COPD; Greenhouse gas emissions

**Key Summary Points**

**Why carry out this study?**

The healthcare sector is one of the largest public sector emitters of carbon globally and will need to achieve significant reductions to achieve net zero carbon targets.

Within the respiratory community, this focus has been on the carbon footprint of preventer pressurised metered-dose inhalers, omitting other relevant factors such as reliever medication and healthcare resource utilisation (HCRU).

The CARBON programme aims to quantify the carbon contribution of these additional aspects of respiratory care in asthma and chronic obstructive pulmonary disease (COPD).

A more holistic understanding as to how respiratory care contributes to greenhouse gas emissions will help identify opportunities for reduction without the potential harm to patients from non-clinically led switching of therapy (for “environmental” reasons).

**What was learned from this study?**

CARBON is an ongoing programme and is the first to quantify the carbon footprint of care of a disease.

Comprising approximately 2.5 million patients from seven studies in more than 40 countries, CARBON aims to calculate the impact of poor disease control and disease progression on the carbon footprint of respiratory care and demonstrate how guideline implementation can improve outcomes and reduce the carbon footprint.

CARBON will help determine whether patients with well-managed disease are likely to have a lower carbon impact overall through reduced requirement for HCRU and lower short-acting β₂-agonist use in order to identify tangible solutions for how a focus on an outcomes-improvement approach in respiratory diseases such as asthma and COPD can help achieve carbon targets.

**INTRODUCTION**

Climate change is the defining challenge of the twenty-first century and is associated with extreme weather events, food scarcity, and worsening of chronic and infectious conditions [1–3]. Based on an urgent need for countries to take concrete steps against this climate emergency, the Paris Agreement, a legally binding international treaty on climate change, was adopted by 196 countries in 2015 [4]. It commits signatories to reduce global warming by limiting the rise in average global temperatures this century to less than 2°C. Signatories will thus need to undertake efforts to limit greenhouse gas (GHG) emissions and become carbon neutral by mid-century.

The healthcare sector is one of the largest public sector contributors of GHGs in many countries, accounting for 10% of the total national emissions in the United States of America (USA) in 2013 [5] and 7% in Australia in 2014–2015 [6]. In Canada, from 2009 to 2015, the healthcare system generated 33 million tonnes of CO₂ equivalents (CO₂e) (primarily from hospitals, pharmaceuticals, and physician services) and over 200,000 tonnes of...
other pollutant emissions [7]. Health damages from healthcare-generated emissions in Canada equated to an estimated 23,000 disability-adjusted life years (DALYs) lost annually, with a range of 4500–610,000 DALYs, reflecting potential uncertainty at each step. In the USA, assessment of a broad sample of emergency medical services agencies in 2011 identified GHG emissions of 660,000–1.6 million tonnes CO₂e/year, with diesel and gasoline consumption accounting for 71.6% of emergency services-related emissions [8]. In England, the carbon footprint from health and social care was 27.12 million tonnes CO₂e in 2017, of which medical instruments/equipment were the largest contributors (13.2%) [9].

Healthcare systems will thus need to achieve substantial reductions in GHG emissions as societies look to decarbonise. The National Health Service (NHS) in the United Kingdom (UK) is the first health service to set emissions targets, aiming to achieve net zero emissions by 2045, with an ambition to reach an 80% reduction by 2036–2039 [10]. Key to this is the ability to quantify the carbon footprint of healthcare practices in a standardised manner. The UK has standardised and validated methodology for quantifying CO₂e for pharmaceuticals and interventions [11] and has also carbon footprinted components of healthcare resource utilisation (HCRU) [12].

Inhaled corticosteroids (ICS) and bronchodilators are the mainstay of treatment for airway diseases and many are delivered via pressurised metered-dose inhalers (MDIs) [13]. MDIs contain hydrofluorocarbon propellants that have high global warming potential (GWP) [14]. As a result, the environmental impact of preventer MDIs has received attention [13, 15]. The development of a next-generation of MDIs that contain propellants with 90–99% less GWP is also underway [16] with the expectation that they will have an impact on reducing total GHG emissions from inhalers from 2025. With more than 500 million people worldwide currently living with asthma and chronic obstructive pulmonary disease (COPD) [17], examining the impact of respiratory care on the environment may provide insights into whether, and how, better management of chronic diseases can lead to greater environmental sustainability. However, the focus on preventer inhalers without considering the contributions made by HCRU, short-acting β₂-agonist (SABA) reliever use, and other medications to the carbon footprint provides an incomplete picture of the carbon impact of respiratory care. Many patients with asthma and COPD remain poorly managed and uncontrolled [18, 19] because of multifactorial reasons, including lack of implementation of treatment guidelines into standard of care [20, 21]. This is exemplified by the widespread overuse of SABA in asthma globally, which in itself is associated with increased risk of exacerbations and hospitalisations [22–24]. Poorly controlled disease and progression will drive increased demand for HCRU [25, 26], and, intuitively, this will carry a higher carbon footprint compared with patients whose disease is well controlled. Conversely, better disease management may reduce reliever use and HCRU and lower the carbon footprint. Thus, attempts to decarbonise respiratory care by focusing on preventer inhalers alone are likely to fall short as they account for only one component of care. Furthermore, there is conflicting evidence of therapeutic equivalence between different inhaler devices with the same active compounds [27, 28], emphasising the requirement for treatment to be personalised to patient needs with the aim of improving outcomes. Non-consensual switching has been associated with worsened asthma control, increased HCRU, and wasted medication [29, 30], which in turn may increase the carbon footprint. Hence, switching of inhalers should only be done as part of a clinical consultation and based on clinical need or patient preference.

The healthCARe-Based envirONmental cost of treatment (CARBON) programme was designed to broaden the understanding of the carbon footprint of respiratory care. This programme aims to quantify the total carbon footprint of care, identify how poor disease management contributes to a larger carbon footprint, and examine whether targeting improvement of care reduces the carbon footprint without compromising patient outcomes.
METHODS
Design of the CARBON Programme

CARBON will quantify the carbon footprint of medications and HCRU among respiratory patients using a combination of certified published studies and methodologies.

Quantification of GHG emissions will be based on the quantity and type of medications sold or prescribed/possessed (as a surrogate for use) and the CO$_2$e emission value of each asthma treatment. To obtain the carbon footprint of all inhaled, including SABA and ICS treatments, as well as oral and injectable medications, SimaPro life cycle assessment software modelling resource and energy consumption data, in addition to Ecoinvent$^{\circledR}$ data sets and certified published studies [31, 32], will be used. To obtain the carbon footprint of HCRU in the UK, emissions data from the Sustainable Healthcare Coalition (SHC) [12] will be used for all healthcare visit types, including travel by the patient and healthcare professional. The carbon footprint of HCRU is currently not available for other countries.

CARBON will use data from seven ongoing studies spanning more than 40 countries and involving approximately 2.5 million patients (Table 1). SABINA CARBON UK will draw from the SABA use IN Asthma (SABINA) UK study [22], with the aim of quantifying GHG emissions associated with asthma care of patients (at least 12 years of age) with well-controlled and not well-controlled asthma. Similar analyses evaluating the carbon footprint associated with poor asthma control are planned in separate studies in the USA (SABA CARBON USA) and Canada (as part of SABA CARBON Europe-Canada).

A second set of studies will use SABA prescription/possession data from SABINA studies as well as inhaler sales data to evaluate emissions linked to SABA use versus all inhaler use, and that of SABA overuse in asthma. The analyses on SABA overuse will be conducted in patients (at least 12 years of age) as part of the SABINA studies [22, 23, 33] in Europe and Canada (SABA CARBON Europe-Canada), USA (SABA CARBON USA) and in other mostly low-and middle-income countries outside of Europe (SABA CARBON International).

In COPD, prior exacerbations are linked to increased likelihood of future exacerbations [26]. The Study of HEalthcare Resource utilisation related to exacerbations in patients with COPD (SHERLOCK) CARBON, an observational cohort study conducted in UK patients (over 40 years of age), will quantify the impact of prior exacerbations on GHG emissions associated with HCRU and SABA use in subsequent years. EXACerbaions and their OutcomeS (EXACOS) CARBON, an observational cohort study, will take this a step further by examining the carbon footprint associated with all aspects of COPD care as well as the influence of disease severity and comorbidities.

Lastly, SABA rEductioN Through ImpleMeNting Hull asthma guidELines (SENTINEL), a quality improvement programme including UK patients (at least 18 years of age) with asthma across six primary care networks in Hull and East Yorkshire, will evaluate the environmental impact associated with system-wide implementation of evidence-based asthma treatment guidelines focused on the use of maintenance and reliever therapy. SENTINEL aims to improve asthma outcomes and reduce SABA overuse through supported guideline implementation and, as a consequence, reduce the environmental impact of asthma treatment.

Ethics and Dissemination

All studies in this programme will be conducted in accordance with the ethical principles consistent with the International Conference on Harmonisation (ICH) guideline for Good Clinical Practice and the Declaration of Helsinki, and all applicable legislation on non-interventional studies and/or observational studies of the countries where the research is conducted.

DISCUSSION

Societies will have to decarbonise all aspects of their economies in the coming years, including healthcare, if nations are to meet their climate
Table 1: Summaries of CARBON studies

| Programme  | SABINA CARBON UK | SHERLOCK CARBON | EXACOS CARBON | SENTINEL Europe-Canada | SABA CARBON International | SABA CARBON USA |
|------------|------------------|-----------------|---------------|------------------------|---------------------------|-----------------|
| CARBON objectives | To quantify GHG emissions associated with asthma care, with a focus on the environmental cost of asthma that is not well controlled. | To evaluate the impact of exacerbation history on GHG emissions associated with HCRU and SABA use in COPD in subsequent years. | To evaluate the carbon footprint associated with COPD care and the effect of disease severity and cardiovascular comorbidities on the carbon footprint. | To evaluate GHG emissions associated with changes in prescribing practice and HCRU after system-wide implementation of The Hull University Teaching Hospitals NHS Trust Guideline for the Treatment of Adult Asthma in patients at risk of poor clinical outcomes due to high SABA use. | To evaluate the volume and carbon footprint of SABA use (versus total inhaler use) in all respiratory conditions and GHG emissions associated with potential SABA overuse in asthma. | To evaluate GHG emissions linked with SABA inhaler use (and overuse in asthma) versus total inhaler use in all respiratory conditions. |
| Study design | Observational open-cohort study | Observational cohort study | Observational cohort study | Non-randomised, stepped-wedge design quality improvement programme | Observational cross-sectional and cohort study | Observational cross-sectional study |
| Study period | 2008–2019 | 2013–2016 | 2010–2018 | 2021–2022 | 09/2018–09/2019 (sales data); 2006–2019 (SABINA I and II data) | 09/2018–09/2019 (sales data); 2019–2020 (SABINA III data) |
|              |                  |                  |              |                  | 09/2018–09/2019 (sales data); 2010–2017 (IBM MarketScan<sup>®</sup>) |
Table 1 continued

| Programme         | SABINA CARBON UK | SHERLOCK CARBON | EXACOS CARBON | SENTINEL | SABA CARBON Europe-Canada | SABA CARBON International | SABA CARBON USA |
|-------------------|------------------|-----------------|--------------|----------|---------------------------|---------------------------|----------------|
| Respiratory indication | Asthma            | COPD            | COPD         | Asthma   | All respiratory uses and asthma | All respiratory uses and asthma | All respiratory uses and asthma |
| Participating countries | UK                | UK              | UK           | UK (6 primary care networks in Hull and the East Riding of Yorkshire healthcare regions) | Bulgaria, Canada, Croatia, Czech Republic, Denmark, France, Finland, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Romania, Sweden, Spain, Switzerland, and UK | Algeria, Argentina, Australia, Brazil, Chile, China, Colombia, Costa Rica, Egypt, Hong Kong, India, Indonesia, Japan, Kenya, Kazakhstan, Kuwait, Malaysia, Mexico, New Zealand, Oman, Peru, Philippines, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Taiwan, Thailand, Turkey, United Arab Emirates, and Vietnam | USA |
| Number of patients | 236,506           | 22,462          | 340,515      | 20,000 (estimated) | 1,131,416                  | 8351                      | 725,499 |
| Age               | ≥ 12 years        | ≥ 40 years      | ≥ 40 years   | ≥ 18 years | ≥ 12 years (SABINA data)     | ≥ 12 years (SABINA data)     | ≥ 12 years (SABINA data)     |
| Programme               | Data source                                      |
|-------------------------|--------------------------------------------------|
| SABINA CARBON UK        | CPRD GOLD, HES, and ONS mortality data          |
| SHERLOCK CARBON         | NHS Greater Glasgow and Clyde Health Board Safe Haven database |
| EXACOS CARBON           | CPRD Aurum and HES                               |
| SENTINEL                | NHS and SUS data sets                           |
| SABA CARBON Europe-Canada | IQVIA™ sales data and SABINA I and II data   |
| SABA CARBON International | IQVIA™ sales data and SABINA III data          |
| SABA CARBON USA         | IQVIA™ sales data and IBM MarketScan® Commercial, Medicare Supplemental, and Multistate Medicaid Research databases |

*CARBON* healthCARE-Based carBON cost of treatment, *COPD* chronic obstructive pulmonary disease, *CPRD* Clinical Practice Research Datalink, *EXACOS* Exacerbations and Their Outcomes, *GHG* greenhouse gas, *HCRU* healthcare resource utilisation, *HES* Hospital Episode Statistics, *NHS* National Health Service, *ONS* Office for National Statistics, *SABA* short-acting β2-agonist, *SABINA* SABA use IN Asthma, *SENTINEL* SABA rEductioN Through ImplemeNting Hull asthma guidELines, *SHERLOCK* Study of HEalthcare Resource utiLisation related to exacerbatiOns in patients with COPD, *SUS* Secondary Uses Services, *UK* United Kingdom, *USA* United States of America

*Prescription/possession data are used as a surrogate for medication use

*b*IQVIA™ Quarterly MIDAS database Q3 2019
change commitments. CARBON, to our knowledge, will be the first programme to systematically quantify the carbon footprint of respiratory care globally to better understand its potentially modifiable contribution to global GHG emissions. Findings from CARBON will help reveal what comprises the carbon footprint of respiratory healthcare, how it is impacted by poor disease control or progression, and how optimal treatments and guideline implementation can drive carbon reduction.

Although reducing carbon emissions is important, it must be achieved without putting patients at risk. Patients with well-managed disease are likely to have a lower carbon impact overall through reduced requirements for HCRU and lower SABA use. CARBON aims to highlight that optimising care through implementation of quality standards and clinical guidelines targeting reductions in SABA use and exacerbation frequency could benefit patients by improving disease control, while at the same time reducing carbon emissions associated with all elements of their care.

**Strengths and Limitations of the Programme**

Strengths of this programme include the following. All CARBON studies use standardised methodology to evaluate the carbon footprint of medications globally. In addition, in the UK, the carbon footprint of HCRU is estimated applying the methodology and data obtained from the SHC guidance enabling quantification of the sustainability performance of care pathways in a consistent and transparent manner. Overall, results from this programme have the potential to promote the development and implementation of effective treatment strategies that will improve patient outcomes, whilst also reducing the carbon footprint of asthma and COPD care. Moreover, once established, the principle of prioritising improvements in patient outcomes, which in turn may elicit environmental benefits, could be applied to other common progressive diseases such as diabetes and chronic kidney disease [34, 35].

A potential limitation of the CARBON programme is that medication prescription and/or sales data are used across studies as a surrogate for actual use. Additionally, only CARBON studies conducted in the UK will initially quantify the carbon footprint of HCRU because of the lack of care pathway guidance in other countries. Lastly, GHG estimates were quantified on the basis of published guidelines and estimates but are subject to some uncertainty. To account for this potential variability, where possible, sensitivity analyses will be conducted using one-tenth to tenfold of recommended HCRU CO2e values.

**CONCLUSIONS**

In CARBON, a detailed mapping of the carbon footprint associated with healthcare will enable a thorough assessment of the environmental impact of treatment and management of respiratory diseases. Output from CARBON has the potential to generate awareness among policy and healthcare decision makers of the carbon footprint of poor care and accelerate innovations to make respiratory care both patient-centric and carbon conscious.

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Prior Presentation. An overview of the CARBON programme has been previously presented at the 10th International Primary Care Respiratory Group World Conference (IPCRG 2021) and encored at the 33rd Annual Conference of the International Society for Environmental Epidemiology (ISEE 2021).

Data Availability. Data sharing is not applicable to this article as it describes the design of a programme and no data sets were generated or analysed.

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