Development of environmental impact calculator for minimally invasive cholecystectomies – study protocol

As part of the ECOMIS project

Abstract:

Introduction:
One of the greatest threats to public health in the 21st century is anthropogenic climate change. Healthcare services worldwide account for 4.9% of global CO2 emissions, with operating rooms being the most resource intensive areas of the hospital. The need for environmentally sustainable change is a priority. Quantitative data and accurate insights into emission are limited, which may hinder adequate comprehension and sustainable decision-making.

Aim:
The aim of this study is to develop and implement a validated, easily accessible, and user-friendly calculator to quantitatively analyze the CO2-eq of minimally invasive surgery, irrespective of country, hospital volume, and hospital income. This quantitative assessment could be used for, but not limited to, problem comprehension, (inter)national benchmarking, research homogeneity, progress assessment, and hospital-specific tailor-made advice on potential improvements.

Method and analysis:
The ECOMIS project follows a multiphase, stepped design. The present study will focus on minimally invasive cholecystectomies. The calculator variables will be selected based on a targeted literature review regarding factors influencing the CO2-eq, with life cycle assessment (LCA) considered the most reliable method in determining environmental impact. This will be carried out via a 3-step process. Step 1: The calculator will be developed based on extensive literature review, followed by step 2: Delphi-study within the ECOMIS expert Steering Committee with the goal of refining and identifying potential improvements. Step 3: External validation of the calculator.

Ethics and dissemination:
The present study has obtained ethical approval by the Bioethics Committee of the University of Warmia and Mazury in Olsztyn, under reference 06/2026.

This project is part of the European Association of Endoscopic Surgery (EAES). The Steering Committee and distribution networks of the EAES will be used for the dissemination of the calculator.

Registration:
Present study is registered in the ISRCTN Registry under code/number …

Discussion:
Present study aims to develop a quantitative environmental impact calculator for minimally invasive surgery based on existing LCA literature. The multidirectional impact of this study could have significant effects on the global CO2-eq of minimally invasive surgery.

Strengths and limitations of this study

- Extensive literature review and an international expert-based steering committee, including general surgeons, HPB surgeons and environmental experts, will be involved in the development of the calculator;
- Present study is the first quantitative calculator to objectively assess the CO2-eq of minimally invasive cholecystectomy;
- Accessible, irrespective of country, hospital volume and income;
- Present study's calculator will offer individual advice based on the outcomes, and can be used for benchmarking, progress assessment and sustainable decision making;
- The present calculator is based on existing literature, generally originating from high-income and middle-income countries, potentially leading to skewed data or bias, which will be addressed during external validation.

Introduction

One of the greatest threats to public health in the 21st century is anthropogenic climate change. Healthcare is estimated to contribute a significant 4.9% of the global carbon dioxide emissions, which exceeds that of the aviation and shipping sectors.[1, 2] Operating rooms generally generate 21-33% of all hospital waste and energy, making them the most resource-intensive areas within hospitals.[3-8]

Recent studies show a growing interest and motivation among surgeons for sustainable decision making in surgery.[9] However, there are a number of barriers to sustainable surgery including lack of information, lack of guidance and support, lack of engagement by surgical teams, absence of a sustainability lead and perceived cost of implementation of green surgery initiatives.[9] The same study identified different priorities in low-income and high-income countries.[9] The top three priorities in low-income countries involve introduction of reusable surgical devices, reduction of consumables and reduction of use of anesthetic gasses, while the high-income countries prioritized recycling, reduction of anesthesia waste and reuse of clinical waste.[10]

The current and most easily implemented efforts in environmental sustainability are mostly aimed at waste recycling in operating rooms with studies reporting up to 30% of waste being recyclable, reducing the carbon footprint by 6%.[11] However, recycling scores low in the 10R impact ladder, since its effect on reducing the production of new products is only marginal.[12]

Despite the growing body of literature on the environmental impact of minimally invasive surgery, this has not resulted in quantitative and objective data that can be translated into impactful decision-making for different hospitals, countries, treatments, and guidelines particularly in minimally invasive surgery (MIS).[6, 13] Differences in healthcare system income, procedural volume, institutional protocols, waste processing logistics, and, general logistics make it difficult to standardize decision-making or offer a step-by-step approach to reduce the environmental impact of minimally invasive surgery.[9]

There is currently no comprehensive analysis in the literature which can assist the surgical healthcare community to make decisions based on quantifiable data in minimally invasive surgery. Life cycle assessments (LCAs) are considered the most robust method of assessing environmental impact, however is very context dependent (source of energy, waste processing, and efficacy of hospital logistics), thus hindering adequate comparison. Moreover, LCAs are very time consuming and research intensive, limiting reproducibility and applicability. Therefore, the aim of this study is to develop and implement a validated, easily accessible, and user-friendly calculator to quantitatively analyze the CO2-eq for minimally invasive cholecystectomies as it is one of the most frequently performed surgical procedures worldwide. The calculator will be accessible and applicable for a broad audience of stakeholders, irrespective of country, hospital volume, and hospital income. This quantitative assessment could be used for, but not limited to, comprehending the problem of the MIS associated CO2-eq, (inter)national benchmarking, research homogeneity, progress assessment, and hospital-specific tailor-made advice on potential improvements.

Methods and analysis

Study Design

This study will follow a multiphase, stepped approach to develop a sustainability calculator for minimally invasive cholecystectomy (MIC). The calculator is part of the Environmental Impact Calculator for Minimally Invasive Surgery (ECOMIS) project. The study protocol was developed in accordance with i) the PRISMA-P guidelines for literature reviews, ii) ACCORD guidelines for consensus studies, and iii) SPIRIT-Outcomes guidelines for reporting study outcomes.[14-16] Present study consists of three main phases: calculator development, expert Delphi consensus survey, and external validation.

METHODS

Phase I: Literature review and variable selection

A systematic literature review will be conducted to identify factors contributing to the CO2-eq of minimally invasive cholecystectomy. The review will follow the Preferred Reporting Items for Systematic Review and Meta-Analyses Protocols (PRISMA-P) guidelines.[17] The primary search will be performed in the Healthcare Life Cycle Assessment (HealthcareLCA) database, a comprehensive and globally recognized repository for LCA studies in healthcare.[18]

A complementary literature review will be performed in Embase, PubMed and Google Scholar to identify potentially relevant studies not indexed in the HealthcareLCA database. The full search strategy will be provided as supplementary material. Studies published from database inception up to 01 April 2026 will be eligible for inclusion. Inclusion criteria comprise original studies performing an LCA of healthcare-related interventions, procedures, logistics, or equipment, reporting environmental impact as kilograms of carbon dioxide equivalents (CO2-eq). Environmental impact is defined as CO2-eq, as this is the most widely accepted and standardized metric for healthcare-related environmental assessments.[5] Studies focusing on cholecystectomy-related procedures or equipment will be prioritized. Exclusion criteria include LCAs of non-medical interventions, non-human studies, studies lacking a clear LCA methodology, or studies not reporting emissions per defined unit (e.g., per procedure).

LCAs are used to quantify or compare the environmental impact of processes or products. The most methodological complete LCA involves analysis of the "cradle-to-grave" impact of individual items including the raw material extraction and production, transport, usage, end-of-life (including cleaning and sterilization and waste disposal).[3, 19] LCAs may vary significantly because of the context specific influences, such as source of energy, waste processing methods, (efficacy of) hospital logistics, travel distance, hospital volume, and treatment protocols.[19] LCAs can be compared and used for environmental decision making, however lack broad applicability based on

the context specific factors, thus comparison should be warranted. Moreover, LCAs are time and resource demanding. Tools like the ECOMIS calculator could be the key for accessible and broad applicable assessment of the environmental impact, thereby supporting sustainable decision making by suggesting environmental improvements, potentially reducing costs, resource use and waste without compromising healthcare outcomes.

From the included studies, variables contributing to carbon emissions will be extracted, categorized, and evaluated based on (1) magnitude of environmental impact and (2) potential modifiability in clinical practice. Variables will be compared based on CO2-eq per procedure. To maintain usability and accessibility, the ten most relevant variables will be selected for inclusion in the sustainability calculator. A preliminary version of the calculator will be developed incorporating these variables. Internal validation will be conducted within hospitals affiliated with the ECOMIS research group to assess feasibility, accuracy, and reproducibility in real-world surgical settings. Feedback obtained during structured online meetings will be used to iteratively refine the calculator.

Phase II: Delphi study within the ECOMIS expert Steering Committee

Phase II aims to optimize the applicability, usability, and clinical relevance of the calculator through expert consensus, following the ACCORD and CREDES recommendations for consensus studies.[15] A modified Delphi methodology will be used to ensure anonymity and iterative feedback.[20] The process will consist of two predefined electronic survey rounds, with the possibility of up to two additional rounds if consensus is not achieved. Surveys will be administered using Castor Electronic Data Capture (EDC), and all responses will be collected anonymously.

An international expert Steering Committee will be convened, consisting of recognized experts in hepatopancreatobiliary surgery, general surgery, environmental sciences, and healthcare sustainability. Experts will be recruited through professional networks within the European Association for Endoscopic Surgery (EAES) and the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES). Invitations will be issued by the ECOMIS study team.

The Delphi questionnaire will be structured across four predefined domains: (1) feasibility, (2) user-friendliness, (3) comprehension, and (4) constraints. Depending on item characteristics, responses will include five-point Likert scales (ranging from strongly agree to strongly disagree), dichotomous responses (agree/disagree), numerical inputs, and free-text comments. The questionnaire will be developed in English. The complete survey tool will be provided as supplementary material.

After each round, quantitative responses and free-text comments will be reviewed and thematically analyzed by the ECOMIS study team. Suggested modifications will be incorporated into subsequent rounds where appropriate.

Consensus will be defined a priori as ≥80% agreement among participating experts, a threshold commonly applied in Delphi studies.[20] To ensure result stability, items reaching consensus must retain consensus in a subsequent round following any revisions.

Statistical analysis:

Cronbach's alpha (α) will be calculated per domain for internal consistency between the experts. A value of ≥0.80 is defined as the cut-off value for determining consensus. Box plots will be constructed showing the median, interquartile range (IQR), maximum, minimum, and mean of the items. The IQR for agreeability of 1 or less on a 5-item Likert scale can be considered as consensus. All analyses will be performed using R (version 3.6.1 or higher). Statistical significance will be defined as $P<0.05$ (two sided) for all analyses.

Phase III: External validation of the calculator.

Phase III will consist of a multicenter external validation study to assess the generalizability, accuracy, and clinical utility of the calculator. Participating centers will include academic and non-academic hospitals performing minimally invasive cholecystectomy across different healthcare systems. For the external validation, the ECOMIS project will collaborate with the Creating A healthieR Environment for FutuRE patiEnts (CAREFREE) project, under supervision of Prof. Dr. Nicole Bouvy.[21, 22]

The CAREFREE project currently investigates the carbon footprint of minimally invasive cholecystectomies in various European centers using LCA analysis. This data support the broad applicability of the present study since it includes different countries, and hospitals.

Validation Objectives

Criterion validity: Agreement between calculator-estimated emissions and reference LCA-derived emissions.

Calibration: Assessment of systematic over- or underestimation across emission ranges.

Statistical Analysis:

Agreement between predicted and observed emissions will be assessed using intraclass correlation coefficients (ICC) and Bland–Altman plots. Calibration will be evaluated using regression analysis and calibration plots. Discriminative performance will be assessed using quantile-based comparisons. Sensitivity analyses will be performed across hospital types and geographic regions. Missing data will be handled using multiple imputation where appropriate.

Storage and access

The sustainability calculator will be hosted on a dedicated website, which has been purchased for a 5-year access period using funds from the EAES grant. The website will be secured and regularly maintained to ensure accessibility and functionality during the study and beyond. All data entered into the calculator will be stored on secure servers in compliance with relevant data protection regulations, ensuring privacy and confidentiality for all involved participants.

Stakeholders / Users

The primary users of the ECOMIS calculator include surgeons, anesthetists, and operating theatre teams performing minimally invasive cholecystectomy. Secondary stakeholders include hospital administrators, sustainability leads, and procurement teams who may use the calculator for benchmarking and quality improvement.

Implementation

After completion of the study, the calculator will be publicly available for end-users to calculate their CO2-eq for minimally invasive cholecystectomies. The calculator can be accessed if users agree that their anonymous data can be used for future research and benchmarking, to further improve the environmental decision-making at the individual hospital level. These results will be published as a survey once sufficient data has been entered.

Expected Outcomes

The ECOMIS calculator is expected to provide a validated, user-friendly calculator for objective assessment of CO2-eq of laparoscopic cholecystectomy. By integrating key variables such as type of anesthesia, waste generation, instrument usage (single-use vs. reusable), and operative time, the calculator will generate accurate and reproducible estimates of environmental impact. This

calculator will offer a standardized approach to sustainability assessment in minimally invasive surgery, allowing surgeons and hospitals to quantify their CO2-eq with precision.

A major anticipated outcome is the establishment of benchmark values for the CO2-eq associated with minimally invasive surgery, starting with laparoscopic cholecystectomy. By creating a standardized framework for CO2-eq analysis, the calculator will help institutions identify areas where sustainable practices can be implemented and improved, ultimately guiding hospital policies and procurement strategies toward more environmentally friendly and sustainable choices.

Through internal validation, the calculator will be tested for feasibility, accuracy, and reproducibility using real-world surgical data. The multicenter evaluation phase will ensure its adaptability across different healthcare settings and surgical workflows, allowing for refinements based on user feedback. This process is expected to confirm the calculator's reliability and highlight any institution-specific factors that may influence sustainability assessments.

In addition to providing quantitative assessment, the ECOMIS calculator aims to identify modifiable factors that contribute to the environmental impact of surgery. By analyzing key contributors such as anesthetic gas choices, disposable instrument usage, and waste management practices, the calculator will offer data-driven insights into areas where carbon emissions can be reduced. This will enable hospitals to implement targeted interventions, such as increasing the use of reusable instruments, optimizing anesthesia protocols, and improving surgical waste management.

In the long term, the calculator is expected to be integrated into routine surgical practice, providing an accessible, web-based platform for ongoing environmental assessments. By making the calculator available for widespread use, the study aims to contribute to broader sustainability efforts within surgery. Additionally, the framework established through this project could be expanded to evaluate the environmental impact of other minimally invasive procedures. Ultimately, the ECOMIS calculator has the potential to influence institutional policies, surgical education, and industry standards, promoting a more sustainable approach to surgical care.

Funding
Funding for the present study will be using EAES Sandpit research grant.

Ethics and dissemination

The present study has obtained ethical approval by the Bioethics Committee of the University of Warmia and Mazury in Olsztyn, under reference 06/2026.

This project is part of the European Association of Endoscopic Surgery (EAES). The Steering Committee and distribution networks of the EAES will be used for dissemination of the calculator and survey.

Consensus data will be published anonymously. Informed consent will be asked of the persons filling in the calculator, to consent with publication of anonymized outcomes of the calculator.

Supplementary

EcoMIS Mini-Delphi — Questionnaire

DOMAIN 1 — Feasibility

1. The calculator is easy to use in its current format.
   (1–5 Likert)

2. The data required are easily obtainable in a typical OR workflow.
   (1–5 Likert)

3. The calculator is feasible for use across various hospital settings, including low-resource environments.
   (1–5 Likert)

4. Are there any settings where using the calculator is not feasible?
   (Free text)

DOMAIN 2 – User-friendliness

1. Completing the calculator would take an acceptable amount of time.
   (1–5 Likert)

2. Time that it took to fill in the calculator?
   (Time in minutes)

DOMAIN 3 – Comprehension

1. The ECOMIS calculator measures the key contributors to the CO2-eq of minimally invasive cholecystectomy.
   (1–5 Likert)

2. The calculator covers the most relevant domains of environmental impact (anesthesia, instruments, waste, operative time).
   (1–5 Likert)

3. The environmental impact variables selected from the literature are appropriately selected based on changeability.
   (1–5 Likert)

4. The outputs of the calculator (CO2-eq) are interpretable.
   (1–5 Likert)

5. The calculator can realistically support sustainability initiatives in operating theatres.
   (1–5 Likert)

6. The calculator should remain globally standardised rather than customised per country.

(1–5 Likert)

DOMAIN 4 – Constraints

1. What is one thing you would change or improve in the calculator?
   (Free text)

2. What is one thing you think absolutely must stay the same?
   (Free text)

3. Do you foresee any barriers in implementing/using this calculator in your institution?
   (Free text)

4. Any additional comments?
   (Free text)

Supplementary

List of ECOMIS Steering Committee

- Prof. dr. Nicole Bouvy	EAES president / CAREFREE principal investigator
- Prof. dr. Patricia Sylla	SAGES past president
- Prod dr. Barbara Seelinger	EAES chair research committee
- Prof. dr. Marc Besselink	IHBPA board
- Prof. dr. Mark van Berge Henegouwen	ISDE research committee
- Dr. Suzanne Gisbertz	EAES program chair
- Dr. Lisa Massey	EAES research committee
- Dr. Stefania Marconi	EAES safety and sustainability taskforce
- Drs. Myrthe Eussen	CAREFREE project coordinator

References

1. WHO Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities: World Health Organisation; [updated 12/10/2020. Available from: https://www.who.int/publications/i/item/9789240012226.
2. Eckelman MJ, Sherman J. Environmental Impacts of the U.S. Health Care System and Effects on Public Health. PLoS One. 2016;11(6):e0157014.
3. Rizan C, Bhutta MF. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. Surg Endosc. 2022;36(6):4067–78.
4. Lee BK, Ellenbecker MJ, Moure-Eraso R. Analyses of the recycling potential of medical plastic wastes. Waste Manag. 2002;22(5):461–70.
5. Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta MF. The Carbon Footprint of Surgical Operations: A Systematic Review. Ann Surg. 2020;272(6):986–95.
6. Tee NCH, Yeo JA, Choolani M, Poh KK, Ang TL. Healthcare in the era of climate change and the need for environmental sustainability. Singapore Med J. 2024;65(4):204–10.
7. Shoham MA, Baker NM, Peterson ME, Fox P. The environmental impact of surgery: A systematic review. Surgery. 2022;172(3):897–905.
8. Mubarak FS. Sustainable Healthcare to Provide Quality Care in the Surgical Industry in the United Kingdom. Cureus. 2023;15(4):e38156.
9. Sathe TS, Alseidi A, Bellato V, Ganjouei AA, Foroutani L, Hall RP, et al. Perspectives on sustainability among surgeons: findings from the SAGES-EAES sustainability in surgical practice task force survey. Surg Endosc. 2024;38(10):5803–14.
10. Reducing the environmental impact of surgery on a global scale: systematic review and co-prioritization with healthcare workers in 132 countries. Br J Surg. 2023;110(7):804–17.
11. Romano L, Giuliani A, Muselli M, Lupi E, Iacomino E, De Nardi P, et al. Toward Environmentally sustainable surgery: Waste recycling in general surgery operating room. Preliminary cognitive audit. World J Surg. 2024;48(11):2637–43.
12. Voukkali I, Papamichael I, Loizia P, Lekkas DF, Rodríguez-Espinosa T, Navarro-Pedreño J, et al. Waste metrics in the framework of circular economy. Waste Manag Res. 2023;41(12):1741–53.
13. MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. Lancet Planet Health. 2017;1(9):e381–e8.
14. Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. Bmj. 2015;350:g7647.
15. Gattrell WT, Logullo P, van Zuuren EJ, Price A, Hughes EL, Blazey P, et al. ACCORD (ACcurate COnsensus Reporting Document): A reporting guideline for consensus methods in biomedicine developed via a modified Delphi. PLoS Med. 2024;21(1):e1004326.
16. Butcher NJ, Monsour A, Mew EJ, Chan AW, Moher D, Mayo-Wilson E, et al. Guidelines for Reporting Outcomes in Trial Protocols: The SPIRIT-Outcomes 2022 Extension. Jama. 2022;328(23):2345–56.
17. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4(1):1.
18. HealthcareLCA Database [Internet]. HealthcareLCA. 2022. Available from: healthcarelca.com/database.
19. Keil M, Viere T, Helms K, Rogowski W. The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments. Eur J Public Health. 2023;33(1):56–63.

20. Diamond IR, Grant RC, Feldman BM, Pencharz PB, Ling SC, Moore AM, et al. Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. J Clin Epidemiol. 2014;67(4):401–9.
21. Comes DJ, Bluiminck S, Kooistra EJ, de Nes L, van Workum FTWE, Touw H, et al. The carbon footprint of a laparoscopic cholecystectomy. BJS. 2024;111(9).
22. Bouvy ND, Davidson MD, Bijlmakers LA, Stobernack T, Eussen MMM, Chambon M, et al. CAREFREE (Creating A healthieR Environment for FutuRE patiEnts) project. Project database: NWO.

Authors' contributions

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Competing interests statement