Accepted: 10 January 2024
DOI: 10.1111/1471-0528.17771

BJOG An International Journal of Obstetrics and Gynaecology

RESEARCH ARTICLE

The carbon footprint of different modes of birth in the UK and the Netherlands: An exploratory study using life cycle assessment

Nienke A. Spil[1,2] | Kim E. van Nieuwenhuizen[3] | Rachel Rowe[4] | Jim G. Thornton[5] | Elizabeth Murphy[6] | Evelyn Verheijen[7] | Clifford L. Shelton[8,9] | Alexander E. P. Heazell[1,6]

[1]Division of Developmental Biology and Medicine, Maternal and Fetal Health Research Centre, School of Medical Sciences, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, UK
[2]University of Groningen, Groningen, The Netherlands
[3]Department of Gynaecology, Leiden University Medical Centre, Leiden, The Netherlands
[4]National Perinatal Epidemiology Unit, Nuffield Department of Population Health, University of Oxford, Oxford, UK
[5]University of Nottingham, Nottingham, UK
[6]Saint Mary's Hospital, Manchester University NHS Foundation Trust, Manchester, UK
[7]Department of Gynaecology, Saxenburgh Medisch Centrum, Hardenberg, The Netherlands
[8]Department of Anaesthesia, Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester, UK
[9]Lancaster Medical School, Lancaster University, Lancaster, UK

Correspondence
Alexander E. P. Heazell, Maternal and Fetal Health Research Centre, Saint Mary's Hospital, 5th floor (Research), Oxford Road, Manchester M13 9WL, UK.
Email: alexander.heazell@manchester.ac.uk

Abstract

Objective: To compare the carbon footprint of caesarean and vaginal birth.
Design: Life cycle assessment (LCA).
Setting: Tertiary maternity units and home births in the UK and the Netherlands.
Population: Birthing women.
Methods: A cradle-to-grave LCA using openLCA software to model the carbon footprint of different modes of delivery in the UK and the Netherlands.
Main Outcome Measures: 'Carbon footprint' (in kgCO_2 equivalents [kgCO_2e]).
Results: Excluding analgesia, the carbon footprint of a caesarean birth in the UK was 31.21 kgCO_2e, compared with 12.47 kgCO_2e for vaginal birth in hospital and 7.63 kgCO_2e at home. In the Netherlands the carbon footprint of a caesarean was higher (32.96 kgCO_2e), but lower for vaginal birth in hospital and home (10.74 and 6.27 kgCO_2e, respectively). Emissions associated with analgesia for vaginal birth ranged from 0.08 kgCO_2e (with opioid analgesia) to 237.33 kgCO_2e (nitrous oxide with oxygen). Differences in analgesia use resulted in a lower average carbon footprint for vaginal birth in the Netherlands than the UK (11.64 versus 193.26 kgCO_2e).
Conclusion: The carbon footprint of a caesarean is higher than for a vaginal birth if analgesia is excluded, but this is very sensitive to the analgesia used; use of nitrous oxide with oxygen multiplies the carbon footprint of vaginal birth 25-fold. Alternative methods of pain relief or nitrous oxide destruction systems would lead to a substantial improvement in carbon footprint. Although clinical need and maternal choice are paramount, protocols should consider the environmental impact of different choices.

KEYWORDS
caesarean section, life cycle assessment, net zero, operating room, sustainability, vaginal birth

1 | INTRODUCTION

Globally around 5% of greenhouse gas emissions originate from health care; in the UK this translates to 25 mega tonnes of carbon dioxide equivalents (CO_2e) emitted by the National Health Service (NHS) per year.[1] Measures to reduce this are a priority and the NHS in England aims to reduce emissions by 80% by 2032 and reach net zero by 2040.[2]

Healthcare professionals need to engage with these efforts, and it is logical to focus on frequently occurring events. Birth is common (~140 M births/year worldwide) and, in many countries, a caesarean birth is the commonest major surgical procedure.[3] The environmental impact of birth and maternity care is increasingly being considered; the American College of Obstetricians and Gynecologists recognises that "climate change is an urgent women's health concern as well as a major public health challenge" and calls for 'healthcare systems to support environmentally responsible practices in order to decrease the environmental impact and carbon footprint of medicine.'[4] Consequently, efforts to address the environmental sustainability of maternity care have been proposed.[5] These can be viewed through the framework: Refuse, Reduce, Reuse, Recycle, Rethink and Research with opportunities for intervention at each level.[6] Given the frequency of birth, and upward trends in caesarean rates, attention to this area could have a significant impact upon the overall 'carbon footprint' of health care. The 'carbon footprint' is a quantitative measure of the direct and indirect greenhouse gas emissions attributable to a process, product, institution or industry usually expressed in CO_2 equivalents (CO_2e)[7]; calculation of the kgCO_2e released provides a common measure of global warming impact that can be used to compare processes and identify areas for reduction (hotspots).[8]

We identified two studies of the carbon footprint of birth. Campion et al.[9] compared caesarean and vaginal birth in the USA, finding that the principal environmental impacts were due to heating and ventilation, waste disposal and single-use resources (e.g. drapes, personal protective equipment [PPE]). However, the scope of this analysis was limited to the second and third stages of labour for vaginal birth and excluded anaesthetics and analgesia. de Ridder et al.[10] from the Netherlands looked at caesarean birth to improve environmental sustainability of the operating room, and identified that the carbon footprint of a caesarean was 11.64 kgCO_2e, largely due to various waste streams. However, no comparison was made with other modes of birth.

In this study, we aimed to estimate the carbon footprint of caesarean birth and vaginal birth in hospital and at home, and the common complications associated with vaginal birth. To account for, and learn from, variation in practice in different, but similarly resourced health systems, we conducted a comparison between the UK and the Netherlands.

2 | METHODS

2.1 | Study design

This study used life cycle assessment (LCA) to quantify the carbon footprint of birth in two settings, Saint Mary's Hospital, Manchester (a tertiary maternity service in the northwest of England ~17 000 births/year) and the Leiden University Medical Centre (a tertiary maternity unit in the west of the Netherlands ~2200 births/year). LCA is commonly used to assess the environmental impact of products and services,[6,11] it is a 'cradle-to-grave' evaluation that includes the production, use and waste disposal of a product or service.[12] This study solely focused on the carbon footprint, although LCA can be used to calculate other environmental impacts. The carbon footprint is the total amount of greenhouse gases that are generated during the whole life cycle of all products and services used during that process, expressed in CO_2e, which allows comparison between different greenhouse gases. The CO_2e is derived from the 100-year global warming potential, which compares the atmospheric release of a greenhouse gas to that of an equal mass of CO_2.

2.2 | LCA goal, scope and system boundaries

The goal of this process-based-LCA was to provide maternity healthcare professionals with insights on how to reduce the carbon footprint associated with childbirth, highlighting the differences between two different settings to learn from each other. The function unit for this study is the birth of a live baby. We evaluated three scenarios in otherwise low-risk pregnancies: (1) planned caesarean birth, from the moment the woman enters the hospital until they leave; (2) uncomplicated vaginal birth in hospital, between the same time points, and (3) uncomplicated vaginal birth at home, from the moment the midwives arrive until they leave. In scenarios (2) and (3), for the UK only, we also considered the most common complications of vaginal birth: (1) vaginal tear/episiotomy suturing (at home or in hospital); (2) forceps birth (hospital only) and (2) ventouse birth (hospital only). The frequency of these complications of vaginal birth were obtained from national data or analysis of the Birthplace data set in the case of home birth.[13,14]

The boundaries of the LCA included the raw material extraction, production and waste of used equipment, sterilisation of reusable equipment, anaesthetics/analgesia, energy usage, laundry and hospital stay (Figure 1). We excluded machines and furniture because of the lack of data on capital goods, their use over prolonged periods of time and their use for processes outside the product system. Linen in the operating room was excluded as this was minimal (single sheet covering the operating table) and not amenable to adjustment. The exclusion of bed sheets in the operating room and labour ward was based on their essential requirement for the beds and the assumption of uniformity across scenarios and diverse locations. We also excluded staff, patient and visitor travel due to lack of data to enable accurate modelling of different modes of transport and their frequency of use.

2.3 | Inventory analysis

Data were collected from Saint Mary's Hospital, Manchester (a tertiary maternity service in the northwest of England with ~17 000 births/year) and the Leiden University Medical Centre (a tertiary maternity unit in the west of the Netherlands with ~2200 births/year). The data were gathered from the following sources: (1) Idemat database, (2) Healthcare LCA database,[15] (3) CCalC2 v2 2016 (which includes Ecoinvent v2.2 2010), (4) data measurements by observation of material usage during vaginal birth and caesarean sections and waste audits in the UK

BJOG An International Journal of Obstetrics and Gynaecology

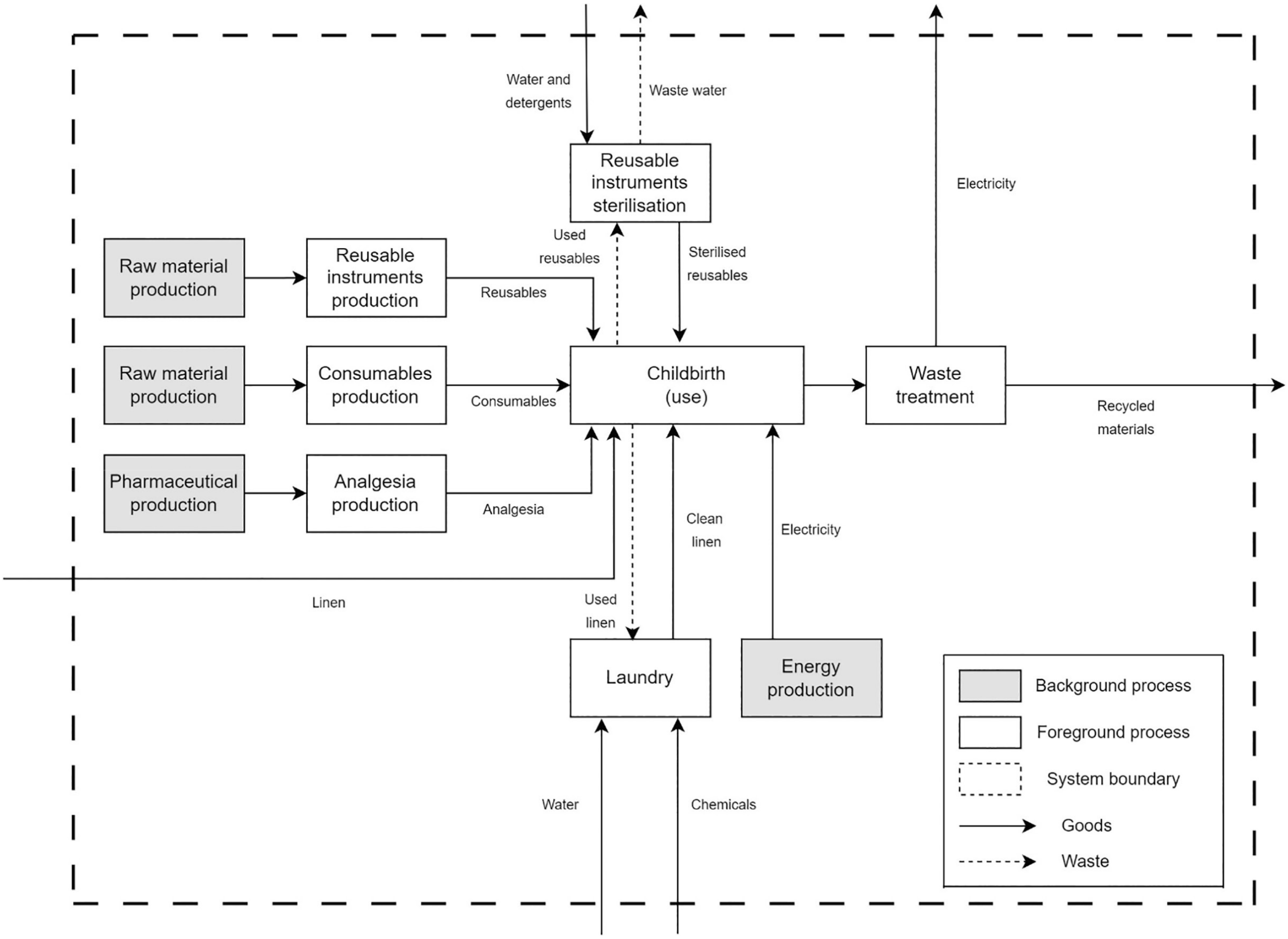


FIGURE 1 Schematic representation of the components considered within the life cycle assessment of different modes of birth. Elements in grey consider background process, e.g. the material and production of items. The system boundary is shown in the dotted line.

and the Netherlands and (5) identification by expert review. By conducting audits for vaginal birth and caesarean section, the amount of equipment used was estimated, the equipment was then weighed and the type of material was noted. For example, equipment for a caesarean birth comprised: a reusable tray with instruments, a disposable pack with consumables, and separately packed consumables such as a urinary catheter and PPE. Equipment for vaginal births comprised a delivery pack, individually packed consumables and PPE. Necessary equipment used in case of complications was determined solely in the UK and included the reusable perineal repair pack, reusable forceps pack, kiwi ventouse and sterile drapes (used for instrumental births or suturing perineal trauma).

Medications and materials used for anaesthesia and analgesia for caesarean and vaginal birth were identified by an expert review with obstetric anaesthetists at Saint Mary's Hospital and recorded from direct observation of procedures. Those included in the LCA were: spinal anaesthesia for caesarean birth, and nitrous oxide 50% with oxygen 50% (N_2O/O_2), intramuscular morphine injection (as a surrogate for opioid analgesia), intravenous patient-controlled analgesia with remifentanil, and epidural analgesia for vaginal birth (see Table 1). N_2O/O_2 was the only analgesia option considered for a home birth. The frequency of usage of different analgesic options was obtained from local and national audit data.[16]

Considering equipment and materials, we used data from different databases to be integrated into our LCA. We integrated data from previously conducted LCAs (identified via the HealthcareLCA database)[15] for equipment and processes already assessed in the literature into our calculations (Appendix S1). When multiple studies were available, more recent studies, those conducted in Europe and those that had a robust design were chosen. Detailed LCAs were available and used for some of the surgical equipment, sterilisation, waste, laundry and analgesia.[17–19] For equipment and/or processes with no previous LCA available, we carried out a bottom-up calculation using the following assumptions and data sources.

2.3.1 | Raw materials

Where possible, individual instruments were weighed. When this was not possible, a complete tray was weighed and estimated packaging was extracted from the total weight. The

TABLE 1 Sources of data regarding frequency of analgesia use and the associated carbon footprint.

Item	Source	Key information	Reference
Frequency of analgesia use (UK)	Care Quality Commission, 2022 survey of women's experiences of maternity care	76% of women used Entonox during labour, 33% used an epidural and 23% used intramuscular pain relief	16
Analgesia carbon footprint	Parvatker et al. Pearson et al.	Estimates of 237.33 $kgCO_2e$ for Entonox, 0.75 $kgCO_2e$ for remifentanil patient-controlled analgesia, 1.2 $kgCO_2e$ for an epidural and 0.08 $kgCO_2e$ for intramuscular morphine	23 25
Carbon footprint – spinal anaesthesia	McGain et al.	Estimate for spinal anaesthesia less oxygen supplementation of 7.14 $kgCO_2e$	12
Length of hospital stay	NHS Maternity Statistics for England from 2021–22	Average hospital stay after a caesarean birth is 1.8 days. Average hospital stay after a spontaneous vaginal birth is 1.13 days.[27]	14
Frequency of complications of vaginal birth	NHS Maternity Statistics for England from 2021–22	Frequency of modes of birth and complications in women with a spontaneous onset of labour were: 71.9% give birth spontaneously, 8.5% have a forceps birth, 5.8% have a ventouse birth and 11.8% have a non-elective caesarean. Perineal tear needing suturing occurs in 41%–49% of vaginal births	14
Frequency of complications of vaginal birth at home	DPhil thesis, L Schroeder, 2013	Estimates of the frequency of perineal trauma were drawn from a micro-costing exercise carried out as part of a cost-effectiveness analysis conducted alongside the Birthplace study	13

smallest possible measurement was 1 g. For consumables, the packaging was assumed to be made of the same material as the product and was not weighed separately. For some products different materials can be used and when the specific material used could not be discerned the most likely material was chosen. When products were made of multiple materials, but the second material was estimated to weigh less than 1 g, all weight was attributed to the first material. Emission factors for raw materials and production were primarily extracted from the Idemat2023 database as this is the most up-to-date and detailed free database.[20] CCalC2 v2 2016 (which includes Ecoinvent v2.2 2010) was used for data about stainless steel production.[21]

2.3.2 | Production

When the production method (e.g. injection moulding, casting) was known, this was added separately. When the production method was unknown, a value that included the production of the raw material was used from the Inventory of Carbon and Energy or Department of the Environment, Food and Regional Affairs (DEFRA) databases.[22,23]

2.3.3 | Use/sterilisation

When materials were reusable, sterilisation of these materials was included. Sterilisation was assumed to take place at the hospital site. Reusable trays were estimated to be used 50 times before being recycled (by discussion with Saint Mary's Hospital theatre staff). Sterilisation data were obtained from the Healthcare LCA database and included decontamination and sterilisation of instruments.[15,24] A sensitivity analysis was conducted to determine the effect of increasing the number of re-uses of equipment for 100, 200 and 300 reuses in total.

2.3.4 | Analgesia

For vaginal birth in hospital, based on the expert review, we assumed a duration of use of 4 h for N_2O/O_2, epidural, remifentanil patient-controlled analgesia and morphine injections. For a home birth we estimated use of N_2O/O_2 to be 700 L; the carbon footprint of N_2O/O_2 based on this volume was calculated to be 182.19 $kgCO_2e$—based on a global warming potential over 100 years of 265.[25] The carbon footprint of analgesic medications was taken from the Healthcare LCA database,[15] and from Pearson et al.[25] where data were not available in the database. Data about spinal anaesthesia were obtained from McGain et al.,[26] though the use of oxygen was subtracted as this is not used for spinal anaesthesia at Saint Mary's Hospital, giving a carbon footprint of 7.14 $kgCO_2e$. The frequency of use of different modes of analgesia was obtained from the 2022 Care Quality Commission maternity care experiences survey for the UK and from Perined in the Netherlands.[16,27]

2.3.5 | Laundry and waste

We used data from Rizan et al.[28] to derive laundry emission factors. We assumed that all waste from a birth was treated as offensive waste, which is first decontaminated and then sent for low-temperature incineration with energy recovery, with the exception of medications and sharps, which are sent for high-temperature incineration, for this reason an estimate of transport to the waste processing site was included.

2.3.6 | Energy

We used data about total energy use per year per floor area of Saint Mary's Hospital Labour Ward to calculate an average value for energy use per square metre.[29] We assumed that a woman in labour would spend 10 h in the birth room in hospital. For home birth, we used data from an energy benchmarking tool and it was assumed that the woman lived in a semi-detached house warmed by gas.[30] Energy use was calculated for 10 h, and floor space in the bedroom was assumed to be the same as in the hospital birth room (29.335 m^2). We used data from MacNeill et al.[31] for energy use in an operating theatre. Caesarean births were assumed to last 1 h with a further hour spent in recovery. It was assumed that operating theatres were in constant use. For recovery, the floor space of the recovery room was multiplied by the same average hospital energy value as the birth room. The DEFRA database was used for energy emission factors.[23] A sensitivity analysis was undertaken based on the varied CO_2e values for energy generation in the UK in 2023 (lowest, lower quartile range, median, upper quartile range and highest).

2.3.7 | Hospital stay

The average hospital stay for each mode of birth was calculated using data from NHS Maternity Statistics for England from 2021–22.[14]

2.3.8 | Exclusions

We did not include data about disposal of the placenta, as this is the same for all modes of birth. The medications oxytocin and syntometrine, and lubricant gel were excluded because no data were available about their carbon footprint.

2.4 | Calculations, modelling and impact assessment

LCA calculations were made in OpenLCA software (v 1.11.0, 2022).[32] To calculate the carbon footprint of equipment the weight of the material was multiplied by a conversion factor for each stage: raw material, production and waste disposal. The carbon footprint was then expressed as CO_2e. The carbon footprints of an average vaginal birth at home and at the hospital were modelled based on published data on the incidence of complications and analgesia use (see Table 1).

The Life Cycle Impact Assessment (LCIA) constitutes the second phase of LCA, aiming to assess the potential environmental impacts linked to a product system by evaluating compiled data obtained from the inventory analysis. This study used Eco-costs 2023 (Version 1.0, Sustainability Impact Metrics) as this is freely available, allowing other researchers to build upon the calculations performed here.

3 | RESULTS

3.1 | Carbon footprint of different modes of birth in the UK

Excluding analgesia and energy, the estimated carbon footprint of a caesarean birth in the UK was 19.24 kgCO_2e (Figure 2A). More than half of that total, 11.6 kgCO_2e, was from disposables (e.g. operating drapes). In comparison, the estimated carbon footprint of a vaginal birth in hospital was 5.64 kgCO_2e, including 2.81 kgCO_2e from PPE. The estimated carbon footprint of a vaginal birth at home was 4.37 kgCO_2e; the hotspot here was PPE (1.47 kgCO_2e, with sterile gloves representing the majority of this amount).

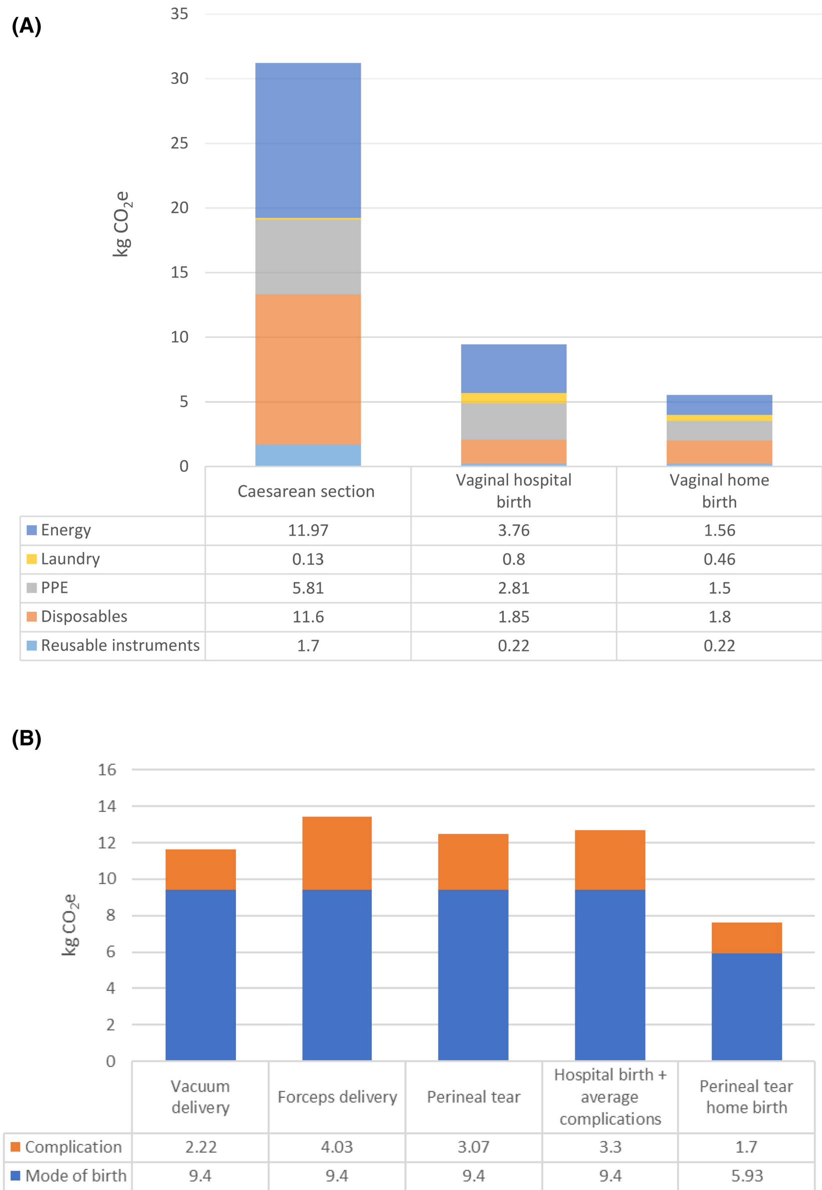
The amount of energy consumed for different modes differed between places of birth. The total energy consumption of a caesarean birth was 11.97 kgCO_2e, comprising an estimated 3.76 kgCO_2e for electricity and 7.77 kgCO_2e for gas in the operating room, and 0.17 kgCO_2e for electricity and 0.27 kgCO_2e for gas used in the recovery area (Figure 2A). The estimated carbon footprint of energy use for a vaginal birth in hospital was lower at 3.76 kg/CO_2e overall (1.48 kgCO_2e of electricity and 2.28 kgCO_2e of gas). The estimated energy use for a home birth was lowest at 1.56 kg/CO_2e (0.26 kgCO_2e for electricity and 1.30 kgCO_2e for gas).

3.1.1 | Complications associated with vaginal birth

The carbon footprint of suturing a perineal tear was 3.07 kgCO_2e in hospital and 1.7 kgCO_2e at a home birth, because fewer sterile drapes and no sterile gown were used at home. The extra carbon footprints of completed ventouse and forceps births were 2.22 and 4.03 kgCO_2e, respectively (Figure 2B). Using the reported frequencies of these complications (Table 1), they add on average a further 4.25 kgCO_2e to a hospital vaginal birth and 2.84 kgCO_2e to a home vaginal birth.

3.1.2 | Analgesia/anaesthesia

There was wide variation in the carbon footprint of vaginal birth according to the type of analgesia used, ranging from 9.48 kgCO_2e for vaginal birth with morphine to 246.73 kgCO_2e for vaginal birth with N_2O/O_2 (Figure 3A). Combining



	Caesarean section	Vaginal hospital birth	Vaginal home birth
Energy	11.97	3.76	1.56
Laundry	0.13	0.8	0.46
PPE	5.81	2.81	1.5
Disposables	11.6	1.85	1.8
Reusable instruments	1.7	0.22	0.22

	Vacuum delivery	Forceps delivery	Perineal tear	Hospital birth + average complications	Perineal tear home birth
Complication	2.22	4.03	3.07	3.3	1.7
Mode of birth	9.4	9.4	9.4	9.4	5.93

FIGURE 2 (A) The carbon footprint (kg CO_2 equivalents [kgCO_2e]) of different modes of birth excluding anaesthesia/analgesia and complications of vaginal birth; (B) The carbon footprint (kgCO_2e) of possible complications during vaginal birth.

the percentages and carbon footprint of the different analgesia gave an average carbon footprint for analgesia per vaginal birth in hospital of 180.79, and 180.37 kgCO_2e for a vaginal birth at home (Figure 3B).

3.1.3 | Overall carbon footprint including hospital stay, analgesia and complications

The estimated total carbon footprint for different modes of birth, including the contributions from mode of birth, energy, analgesia use, common complications and duration of hospital stay, were 119.35 kgCO_2e for caesarean birth, 245.28 kgCO_2e for vaginal birth in hospital, and 190.96 kgCO_2e for vaginal birth at home (Figure 3B).

3.2 | Comparison of carbon footprint of mode of birth in the UK and the Netherlands

The total carbon footprint of caesarean birth in the Netherlands was marginally higher than in the UK (32.96 versus 31.21 kgCO_2e) (Figure 4A). This was due to the greater amount of consumables and PPE. Excluding analgesia and energy consumption, the carbon footprint of vaginal birth in the Netherlands was lower than in the UK in both hospital and home settings (10.74 versus 12.47 kgCO_2e and 6.27 versus 7.63 kgCO_2e, respectively; Figure 4A). This was due to less use of PPE and consumables. When analgesia for vaginal birth was considered, the relatively less frequent use of N_2O/O_2 in the Netherlands resulted in an average carbon footprint for vaginal birth including analgesia that was

 BJOG An International Journal of Obstetrics and Gynaecology

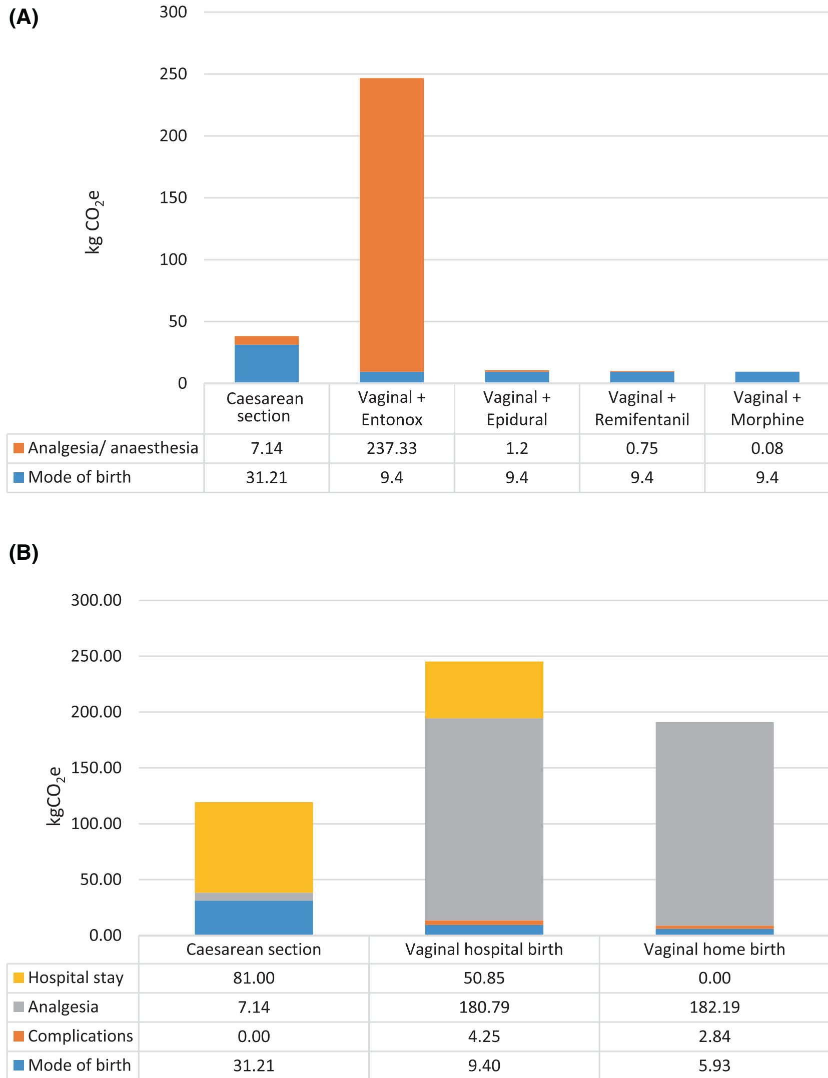


FIGURE 3 (A) The carbon footprint (kg CO_2 equivalents [kgCO_2e]) of caesarean and hospital vaginal birth, including spinal anaesthesia (caesarean) and different types of analgesia for a vaginal hospital birth; (B) The carbon footprint (kgCO_2e) of different modes of birth including average anaesthesia/analgesia, complications for vaginal births, and hospital stay.

much lower in the Netherlands than in the UK (11.64 versus 193.26 kgCO_2e) (Figure 4B).

3.3 | Sensitivity analyses

The overall carbon footprint is relatively insensitive to additional pack reuses above 50 (Table S1A). The average reduction in carbon footprint per use for 300 reuses compared with 50 was 8.59%. In real terms, for a caesarean section in the UK this was 0.36 kgCO_2e or ~1% of the total for the procedure. Given that approximately 10% of the total carbon footprint related to energy use, variation in the kgCO_2e of the electricity supplied had a greater impact, varying over two-fold between the upper quartile and lower quartile of kgCO_2e for UK energy supply (e.g. 3.60 kgCO_2e versus. 1.57 kgCO_2e per caesarean section, Table S1B). Achieving emissions currently on the lower quartile would reduce the impact of a caesarean birth in the UK by approximately 7%.

4 | DISCUSSION

Excluding analgesia/anaesthesia, the carbon footprint of a caesarean is higher than that of a vaginal birth and there is little difference between vaginal birth in hospital or at home. However, the use of N_2O/O_2 for analgesia increases the carbon footprint of a vaginal birth 25-fold, such that, at many levels of N_2O/O_2 use, vaginal birth has a greater carbon footprint than caesarean. In the Netherlands, where N_2O/O_2 is used less frequently than in the UK, vaginal birth has a much lower carbon footprint. Other large contributors to the carbon footprint for different modes of birth include disposables (including PPE), instruments and energy.

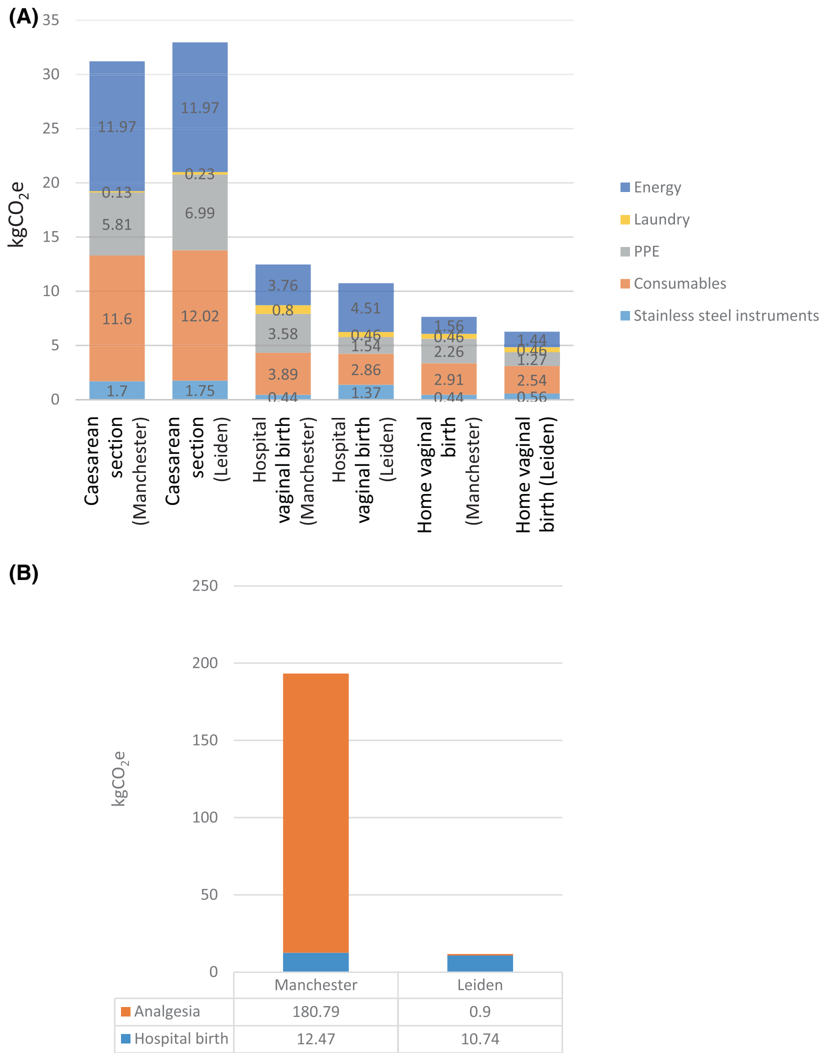


FIGURE 4 (A) The carbon footprint (kg CO_2 equivalents [kgCO_2e]) of caesarean and vaginal birth in the UK (Manchester) and the Netherlands (Leiden), excluding anaesthesia/analgesia; (B) The carbon footprint of hospital vaginal birth including complications with analgesia in the UK (Manchester) and the Netherlands (Leiden).

4.1 | Strengths and limitations

We included as many components of the selected mode of birth as possible, and our bottom-up calculation is more reliable than a top-down one. Existing data were supplemented with contemporary observations and audits from two busy maternity units. We were also able to make comparisons between different modes of birth in two countries.

The main weakness is that we considered idealised births in low-risk pregnancies ending by the route planned. In the real world, labour may start in one location, end in another, and the mode of birth may change or complications may develop. We did not account for this complexity in our calculations; however, the data between modes of birth and settings were comparable, allowing identification of 'environmental hotspots' and learning how these can be improved.

The duration of labour and the use of analgesia may differ widely between individuals, which would cause large individual differences between cases, particularly where N_2O/O_2 is used. Our calculations are based on a representative average, which aims to usefully describe a population but should not be ascribed to any particular individual. Future analyses would be strengthened by individual observations on analgesia usage and modelling of the frequency of complications. We included hospital stay in our LCA, but used data from general wards that may not be generalisable to the postnatal ward. We were also not able to include staff and visitor transport to the hospital, which is likely to add to the carbon footprint of hospital-based birth; transfer to hospital in the case of home birth also needs to be considered in future analyses.

4.2 | Interpretation

Our findings are consistent with those of Campion et al.,[9] who showed that a vaginal birth (excluding analgesia) has less than 50% of the carbon emissions of a caesarean birth. They reported that energy use contributed more than 50% of the total carbon footprint for both caesarean and vaginal births, while we estimated that energy use accounts for about a third of the carbon footprint; this difference might stem from differences in the use of renewable energy sources between countries.[9] de Ridder et al.[10] reported a carbon footprint of 11.64 $kgCO_2e$ for caesarean, which is lower than our estimate. However, their system boundaries excluded the sterilisation of reusable instruments and laundry. When comparing the carbon footprint of caesarean birth with other lower abdominal surgery, Rizan et al. reported a carbon footprint of 11.7 $kgCO_2e$ (range 10.1–15.0) for an inguinal hernia repair excluding energy use or anaesthesia (less than our estimate for caesarean birth, 31.21 $kgCO_2e$). Interestingly, the production, waste disposal and packaging of disposables accounted for 68% of their calculated carbon footprint, which is comparable to 60% in our LCA.[19]

The findings of this study can be contextualised by more commonly understood principles for reducing one's carbon footprint: Refuse, Reduce, Reuse, Recycle, Rethink and Research.[6] This framework can help to generate specific suggestions to reduce the environmental impacts of maternity care. Many people are concerned about the environmental impact of healthcare; a survey of 1858 adults in the UK, found 70% supported choosing an environmentally friendly alternative and 65% would consider environmental impact as part of deciding on treatment.[33] But the UK National Institute of Health and Care Excellence (NICE) identified limited public knowledge about the link between health care and climate change and there were concerns that sustainability means 'somebody loses out'.[34] Individuals may be unwilling to make trade-offs between their care and the environment. Nevertheless, increasing awareness of both professionals and the public of the environmental impact of healthcare choices is essential if these tensions are to be resolved.[35] As caesarean birth has a three times higher carbon footprint than vaginal birth, without analgesia, the environmental impact of caesarean for non-medical reasons should be considered.

Eleftheriades et al.[5] proposed a framework to reduce the carbon footprint of obstetrics including: reducing paper and plastic waste, minimising unnecessary PPE and informing obstetricians about toxic environmental agents so that they can perform environmental risk assessment and offer relevant clinical counselling. First, the environmental impact of N_2O/O_2 use in maternity needs to be urgently addressed. Due to its embedded nature in maternity care in many health systems, and the importance of ensuring maternal choice of pain relief, it cannot simply be removed or replaced with other forms of analgesia. In line with recommendations from the Health Foundation and NICE, we propose that pregnant women should be informed about their analgesic options for birth, including their wider impacts, and although they should be free to choose the analgesia of their preference, N_2O/O_2 should not be presented as the only or best option available. Where N_2O/O_2 is used, catalytic destruction systems can reduce its ambient levels in the delivery room by 71%–81%, indicating potential environmental benefits.[36] In our LCA, the destruction of 71%–81% of the N_2O/O_2 would lead to a reduction of 194–221 $kgCO_2e$ for vaginal birth, making the total carbon footprint similar to that of a caesarean.

This study showed that about a third of the carbon footprint of a caesarean was due to the use of disposables, and another third from the use of reusable instruments. Reduced use of disposable instruments has been considered elsewhere (e.g. critical care) where procedure packs with reusable metalware, surgical trays, containers, drapes and gowns have saved money and reduced waste.[37] Ideally, all plastic disposables should be made from either bioplastics or recycled plastic (and go on to be recycled), and instrument packs should be evaluated to ensure that only essential instruments are included. Notably, Ridder et al.[10] reduced their carbon footprint of caesarean birth by 2.5 $kgCO_2e$ by adjusting the contents of the surgical pack.

PPE is a large component of the environmental impact of vaginal birth, mostly due to sterile gloves. The carbon footprint of vaginal birth was lower in Leiden, where non-sterile gloves are used in labour unless there is an indication for sterile PPE, e.g. preterm rupture of membranes. Morshedi et al.[38] showed that wearing normal gloves instead of sterile gloves during vaginal examinations in labour did not increase the risk of infection. Thus, the number of sterile gloves could be safely reduced. Furthermore, there is expanding interest in replacing disposable gowns with reusable ones, which can provide better protection and are more economic[39]; reusable gowns reduce greenhouse gas emissions by 66% and water consumption and solid waste by 80%, compared with disposable gowns.[40]

Further work is needed to add to the LCA to make it more comprehensive by incorporating the environmental impact of other complications, e.g. postpartum haemorrhage or transfer between settings. This will be facilitated by acquisition of large-scale routinely collected data from maternity care systems that include complex patient journeys (e.g. Maternity Services Data Set in the UK). This will allow identification of other areas to reduce the carbon footprint. In addition, future LCA should consider other factors such as acidification and air pollution to give a broader assessment of environmental impact of births. Furthermore, the environmental impact of other areas of maternity care, including prenatal and postnatal care also need to be assessed. Novel approaches in teleconferencing and telemonitoring interventions in prenatal care merit assessment to determine whether they can reduce the carbon footprint of patient travel.[41]

5 | CONCLUSIONS

This study offers opportunities for clinicians and pregnant women to make more informed decisions about the carbon footprint of birth. We propose that for every new intervention, environmental impact should be considered alongside health and cost-effectiveness, and that this 'triple assessment' should also be used to examine established maternity care procedures, to optimise their environmental impact.

AUTHOR CONTRIBUTIONS

NAS and AEPH contributed to all aspects of the study design. NAS, AEPH, RR, CLS and JGT developed the initial study protocol. NAS and KEN undertook the inventory analysis with assistance from EM. NAS undertook the LCA calculations. NAS and AEPH obtained data from online sources. All authors were responsible for discussion of the data and contributed to the drafting of the manuscript. All authors gave approval for the final version of the manuscript.

ACKNOWLEDGEMENTS

We are grateful to Megan Richold from the Manchester University NHS Foundation Trust Sustainability Team for her enthusiasm and guidance and to Dr Liz Schroeder of the Nuffield Department of Primary Care Health Sciences at the University of Oxford for her suggestions about resource use.

FUNDING INFORMATION

This study received no specific funding.

CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Supporting Information of this article.

ETHICS APPROVAL

This study used publicly available data and non-identifiable data so did not require ethical approval.

ORCID

Kim E. van Nieuwenhuizen https://orcid.org/0000-0001-8531-4778
Rachel Rowe https://orcid.org/0000-0003-2994-3240
Jim G. Thornton https://orcid.org/0000-0001-9764-6876
Clifford L. Shelton https://orcid.org/0000-0002-8438-398X
Alexander E. P. Heazell https://orcid.org/0000-0002-4303-7845

REFERENCES

1. Tennison I, Roschnik S, Ashby B, Boyd R, Hamilton I, Oreszczyn T, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. Lancet Planet Health. 2021;5(2):e84–e92.
2. NHS England. Delivering a net zero NHS. 2023 [cited 2023 Apr 27]. Available from: https://www.england.nhs.uk/greenernhs/a-net-zero-nhs/
3. Boerma T, Ronsmans C, Melesse DY, Barros AJD, Barros FC, Juan L, et al. Global epidemiology of use of and disparities in caesarean sections. Lancet. 2018;392(10155):1341–8.
4. American College of Obstetricians and Gynecologists. Addressing climate change – position statement. 2021 [cited 2023 Jul 11]. Available from: https://www.acog.org/clinical-information/policy-and-position-statements/position-statements/2021/addressing-climate-change
5. Eleftheriades A, Tsagkaris C, Gozderesi Y, Panagopoulos P. Making obstetrics more environmentally sustainable during and beyond the COVID-19 pandemic. Int J Health Plann Manage. 2022;37(5):2992–6.
6. Baid H, Damm E, Trent L, McGain F. Towards net zero: critical care. BMJ. 2023;381:e069044.
7. Wright LA, Kemp S, Williams I. 'Carbon footprinting': towards a universally accepted definition. Carbon Manag. 2011;2(1):61–72.
8. Core Writing Team. Climate change 2023: synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the Intergovernmental Panel on Climate Change. Geneva: IPCC; 2023.
9. Campion N, Thiel CL, DeBlois J, Woods NC, Landis AE, Bilec MM. Life cycle assessment perspectives on delivering an infant in the US. Sci Total Environ. 2012;425:191–8.
10. de Ridder EF, Friedericy HJ, van der Eijk AC, Dankelman J, Jansen FW. A new method to improve the environmental sustainability of the operating room: healthcare sustainability mode and effect analysis (HSMEA). Sustainability. 2022;14:13957.
11. Guinee JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, et al. Life cycle assessment: past, present, and future. Environ Sci Technol. 2011;45(1):90–6.
12. McGain F, Muret J, Lawson C, Sherman JD. Environmental sustainability in anaesthesia and critical care. Br J Anaesth. 2020;125(5):680–92.
13. Schroeder L. The cost-effectiveness and efficiency of intrapartum maternity care in England. Oxford: University of Oxford; 2013.
14. NHS Digital. NHS Maternity Statistics, England – 2021–22. 2023 [cited 2023 Apr 27]. Available from: https://digital.nhs.uk/data-and-information/publications/statistical/nhs-maternity-statistics/2021-22
15. Drew J, Rizan C. HealthcareLCA Database. 2022 [cited 2023 Apr 27]. Available from: www.healthcarelca.com/database
16. Care Quality Commission. 2022 Survey of women's experiences of maternity care. Newcastle Upon Tyne: Care Quality Commission; 2023.
17. Quintana-Gallardo A, Del Rey R, Gonzalez-Conca S, Guillen-Guillamon I. The environmental impacts of disposable nonwoven fabrics during the COVID-19 pandemic: case study on the Francesc de Borja hospital. Polymers (Basel). 2023;15(5):1130.
18. Jamal H, Lyne A, Ashley P, Duane B. Non-sterile examination gloves and sterile surgical gloves: which are more sustainable? J Hosp Infect. 2021;118:87–95.
19. Rizan C, Lillywhite R, Reed M, Bhutta MF. The carbon footprint of products used in five common surgical operations: identifying contributing products and processes. J R Soc Med. 2023;116:199–213.
20. Sustainability Impact Metrics. Excel files: Idemat and Ecoinvent, and eco-costs midpoint tables. 2023 [cited 2023 Apr 27]. Available from: https://www.ecocostsvalue.com/data-tools-books/
21. Sustainable Industrial Systems Research Group. CCaLC2 for windows carbon footprinting tool. 2023 [cited 2023 Apr 27]. Available from: http://www.ccalc.org.uk/ccalc2.php
22. Circular Ecology. Inventory of carbon and energy. 2023 [cited 2023 Apr 27]. Available from: https://circularecology.com/embodied-carbon-footprint-database.html
23. Parvatker AG, Tunceroglu H, Sherman JD, Coish P, Anastas P, Zimmerman JB. Cradle-to-Gate Greenhouse Gas Emissions for Twenty Anesthetic Active Pharmaceutical Ingredients Based on Process Scale-Up and Process Design Calculations. ACS Sustainable Chem Eng. 2019;7(7):6580–91.
24. Rizan C, Lillywhite R, Reed M, Bhutta MF. Minimising carbon and financial costs of steam sterilisation and packaging of reusable surgical instruments. Br J Surg. 2022;109(2):200–10.

25. Pearson F, Sheridan N, Pierce JMT. Estimate of the total carbon footprint and component carbon sources of different modes of labour analgesia. Anaesthesia. 2022;77(4):486–8.
26. McGain F, Sheridan N, Wickramarachchi K, Yates S, Chan B, McAlister S. Carbon footprint of general, regional, and combined anesthesia for total knee replacements. Anesthesiology. 2021;135(6):976–91.
27. Perined Collaboration. Perined database. 2023 [cited 2023 Apr 27]. Available from: https://www.perined.nl/
28. Rizan C, Bhutta M, Reed M, Lillywhite R. The carbon footprint of waste streams in a UK hospital. J Clean Prod. 2021;286:125446.
29. Prashant V. Display energy certificate (DEC). 2023 [cited 2023 Apr 27]. Available from: https://find-energy-certificate.service.gov.uk/energy-certificate/8429-2498-9018-3500-6793
30. CIBSE. Energy benchmarking dashboard. 2023 [cited 2023 Apr 27]. Available from: https://www.cibse.org/knowledge-research/knowledge-resources/knowledge-toolbox/energy-benchmarking-tool
31. 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–e388.
32. Ciroth A, Srocka M, Hildenbrand J. OpenLCA. 1.10.2 ed. 2023 [cited 2023 Apr 27]. Available from: https://www.openlca.org
33. Cameron G, Göpfert A, Gardner T. Going green – what do the public think about the NHS and climate change? London: Health Foundation; 2021.
34. National Institute for Health and Care Excellence. NICE listens: public dialogue on environmental sustainability. Manchester: National Institute for Health and Care Excellence; 2023.
35. van Nieuwenhuizen KE, Both I, Porte PJ, van der Eijk AC, Jansen FW. Environmental sustainability and gynaecological surgery: which factors influence behaviour? An interview study. BJOG. 2023. https://doi.org/10.1111/1471-0528.17709
36. Pinder A, Fang L, Fieldhouse A, Goddard A, Lovett R, Khan-Perez J, et al. Implementing nitrous oxide cracking technology in the labour ward to reduce occupational exposure and environmental emissions: a quality improvement study. Anaesthesia. 2022;77(11):1228–36.
37. McGain F, McAlister S, McGavin A, Story D. A life cycle assessment of reusable and single-use central venous catheter insertion kits. Anesth Analg. 2012;114(5):1073–80.
38. Morshedi B, Strohm S, James H, Springer C, Gould L, Thurman A, et al. Effect of sterile vs clean gloves for cervical checks in labor on maternal infection at term: a randomized trial. Am J Obstet Gynecol MFM. 2023;5(6):100931.
39. McQuerry M, Easter E, Cao A. Disposable versus reusable medical gowns: a performance comparison. Am J Infect Control. 2021;49(5):563–70.
40. Vozzola E, Overcash M, Griffing E. An environmental analysis of reusable and disposable surgical gowns. AORN J. 2020;111(3):315–25.
41. Bekker MN, Koster MPH, Keusters WR, Ganzevoort W, de Haan-Jebbink JM, Deurloo KL, et al. Home telemonitoring versus hospital care in complicated pregnancies in the Netherlands: a randomised, controlled non-inferiority trial (HoTeL). Lancet Digit Health. 2023;5(3):e116–e124.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Spil NA, van Nieuwenhuizen KE, Rowe R, Thornton JG, Murphy E, Verheijen E, et al. The carbon footprint of different modes of birth in the UK and the Netherlands: An exploratory study using life cycle assessment. BJOG. 2024;00:1–11. https://doi.org/10.1111/1471-0528.17771