Appendix 1. Evidence table for LCA studies bij module Operatietechnieken

Study reference	Journal	Study characteristics	Methods	Data collection	Outcomes	Interpretation	Comments
Power (2012)	Journal of Endourology Journal information Peer-reviewed journal exclusively focused on minimally invasive and robotic urology, applications, and clinical outcomes. Critical review: Peer reviewed article. Not in specific LCA journal.	Type of study: LCA Objective: To assess the additional climate impact of minimally invasive surgery (MIS) as compared with traditional open surgery (where MIS includes both laparoscopy and robotically-assisted laparoscopy to achieve cholecystectomy, appendectomy, bariatric surgery, colon surgery, hysterectomy, salpingo-oophorectomy/tubal ligation, prostatectomy, nephrectomy, and natural orifice surgeries) LCA-method: EIO-LCA (GHG Protocol) Setting and country: Inpatient and outpatient clinics in the US Facility: Memorial Sloan-Kettering Cancer Center, New York City, NY, USA Years of data collection: 2009 Surgical discipline(s): Gastroenterology, Obstetrics & Gynecology, Urology & Nephrology	Goal and scope[1]: Quantitate the carbon footprint of MIS in the US Functional unit(s)[2]: One year of minimally invasive surgical procedures performed in the United States (2009; n=2,520,223) System boundaries: Operating theatre door to door (intraoperative period, inferred from text) Included stages: Pharmaceuticals (transport, capture and compression included), disposal Stated excluded components: Production, (other) transport, energy use, reuse, non-CO2 pharmaceuticals (all other lifecycle stages were considered equivalent to open surgery/laparotomy) Inventory database: - Allocation: No Normalization & Weighting: No	Minimally invasive surgeries' CO_2 footprint is based on used CO_2 for insufflation (transport, capture, compression, packaging and use) and disposal of surgical instruments (laparoscopic trocars). All other emissions were considered equivalent to open surgery. For transportation the Memorial Sloan-Kettering Cancer was used as index case. Number of miles for CO_2 cylinders were calculated. Carbon footprint calculator based on U.S. Department of Transportation (US DOT) fuel efficiency data and Greenhouse Gas Protocol initiative (GHGPI) mobile guides were used to estimate the carbon emissions. Carbon dioxide capture and compression were calculated using the Input-Output Life cycle assessment (EIO-LCA) model (i.e. based on economic activity of the largest medical CO_2 supplier). To calculate the annual use of CO_2 for MIS the number of procedures were identified in national databases. Average operative times were	1. Climate Change • CO_2 emission used for insufflation: 303 tonnes CO_2 • CO_2 emission from CO_2 capture/compression: 351,400 tonnes CO_2. Wherein 251,000 can be attributed to industrial gas manufacturing, 83,700 to power generation and supply and 16,700 to gas extraction. • CO_2 emission used for transportation: 2970 tonnes CO_2 • CO_2 emission from incineration of disposable instruments (laparoscopic trocars and robotic instruments): 1251 Tonnes CO_2 Total CO_2 emissions from minimally invasive surgery were estimated at 355,924 tonnes/year more in comparison to open surgery. 2. Waste A total of 208,441 kg of plastic biomedical waste from disposable trocar and laparoscopic instrument use for MIS per year. This consisted of 186,000 kg of plastic from laparoscopic trocars (6,200,000 trocars) and 22,441 kg of plastic from robotic instruments. 3. Acidification	This LCA of MIS in the US, shows that the biggest contributor in CO_2 emissions is the capture/compression of CO_2 for insufflation. The industrial gas manufacturing in this part contributes most. Followed by the actual use of the CO_2 for insufflation, the transportation of the gas and the incineration of the disposable instruments.	Authors conclusion The CO_2 emissions of MIS in the US, when considering both direct and indirect factors, have a significant environmental impact. This should be considered to reduce healthcare's CO_2 footprint while maximizing healthcare quality. Limitations study Not all disposable instruments were included in the analysis and emissions related to e.g. the manufacturing process, transportation and energy use of the disposable instruments were not taken into account. Emissions related to the preoperative and postoperative stay were not included. This can vary between the different surgery procedures and the length of this stay can have an effect on the eventual CO_2 footprint. . Next to that, electricity use was considered equivalent, however it is expected to differ between the operating techniques. In particular MIS versus open surgery. MIS uses electricity driven instruments and cameras and thereby the robot

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		Funding and conflict of interest: Supported by The Sidney Kimmel Center for Prostate and Urologic Cancers and by Award Number U54CA137788/U54CA132 378 from the National Cancer Institute. No competing financial interests exist.	Impacts reported: Yes Contribution analysis: Yes Scenario analysis: No Comparative analysis: No Sensitivity analysis: No Uncertainty analysis: No Variance analysis: No	estimated based on institutional data. Number of cylinders and CO_2 emissions were calculated from this data. Data for the number of disposable instruments, specifically laparoscopic trocars, were obtained from US market engineering research (2004). Weight of a laparoscopic trocar was estimated. Data for robot-assisted procedures were based on Intuitive Surgical procedure numbers, instrument catalogue unloaded weights an using a general rule of 10 uses before disposal. The carbon footprint was estimated with the assumption that incinerating 1 kg of plastic produces approximately 6 kg of CO_2.	No results in this study. 4. Eutrophication No results in this study. 5. Human Toxicity No results in this study. 6. Ecotoxicity No results in this study. 7. Ozone Depletion No results in this study.		uses robotic arms which require electricity.
Woods (2015)	International Journal of Medical Robotics and Computer Assisted Surgery Journal information International Journal of Medical Robotics and Computer Assisted Surgery is a cross-disciplinary journal presenting the latest developments in robotics and computer assisted	Type of study: LCA Objective: To assess the climate impact three surgical modalities for endometrial cancer staging: laparotomy, laparoscopy, robotic-assisted laparoscopy LCA-method: Attributional LCA (PAS 2050, GHG Protocol)	Goal and scope[1]: Quantitate the CO_2 footprint of robotically-assisted laparoscopy (RA-LSC), laparoscopy (LSC) and laparotomy (LAP) Functional unit(s)[2]: One endometrial staging procedure System boundaries: Operating theatre door to door (intraoperative period, inferred from text)	150 staging procedures (50 per arm) for endometrial cancer for the three surgical modalities were reviewed. Collected information: patient age, body mass index (BMI), procedure type, operative time, history of prior abdominal surgery, length of stay, uterine weight and instruments used. Waste production and energy expenditure were determined for each	1. Climate change The CO_2 footprint for all 150 endometrial staging procedures, including solid waste and energy consumed, was corresponding with 4498 CO_2e, averaging 30 kg CO_2e/patient. A robotically-assisted laparoscopy (RA-LSC) procedure resulted in a CO_2 footprint of 40.3 kg CO_2e/patient, based on energy use and waste. The CO_2 emission from this energy	Comparing the three surgical modalities, the RA-LSC turns out to have the biggest CO_2 footprint. Emissions from both energy use and waste are greatest in the RA-LSC group. The energy use of all groups seem comparable, but because of the use of the Da Vinci robot, the RA-LSC energy consumption turns out highest. The energy use	Authors conclusion An increased environmental impact of RA-LSC and LSC over LAP is identified. The future healthcare sustainability research should include development of strategies to mitigate the environmental effects of healthcare while improving safety, quality and cost-effectiveness. Limitations

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	technologies for medical applications. Critical review: Peer reviewed article. Not in specific LCA journal.	 Setting and country: Hospital in the US Facility: Albert Einstein College of Medicine, New York City, NY, USA Years of data collection: 2008-2011 Surgical discipline(s): Obstetrics & gynecology; Oncology Funding and conflict of interest: The authors declare no potential conflicts of interest.	 Included stages: Energy, waste/disposal Stated excluded components: Production, transport, pharmaceuticals, reuse Inventory database: - Allocation: No Normalization & Weighting: No Impacts reported: Yes Contribution analysis: Yes Scenario analysis: No Comparative analysis: Yes Sensitivity analysis: No Uncertainty analysis: No Variance analysis: Yes (ANOVA) Characteristics of study population by surgical modality	surgical modality and included in the analysis. Solid waste was determined by weighing items used within procedures (drapes, gowns, gloves, consumables, sterile wrap, single-use devices) and multiplying weights by use data taken from OR records. Energy consumption was determined by using operative time records and multiplying duration of the procedure per unit time of four categories: environmental (HVAC, lighting), equipment, instruments, robotic system. Assessment methodology was adapted from the British Standards Institute Publicly Available Specification 2050 (BSI PAS 2050) and the Greenhouse Gas Protocol. Data on energy and waste were obtained from the National Energy Foundation (NEF), the US Energy Information Administration and previous studies.	use was 26 kg CO_2, calculated by energy use (kWh) and operative time (min). A laparoscopy (LSC) procedure emitted 29.2 kg CO_2e/patient. The CO_2 emission from this energy use was 18 kg CO_2. A laparotomy (LAP) resulted in the emission of 22.7 kg CO_2e/patient. The CO_2 emission from this energy use was 14.4 kg CO_2. 2. Waste The RA-LSC group produced a total amount of 14.3 kg (14.3 kg CO_2e/patient) of solid waste, which existed of 6.90 kg consumable waste (6.90 kg CO_2e/patient), 2.47 kg single-use device waste (2.47 kg CO_2e/patient), 4.03 kg infection control waste (4.03 kg CO_2e/patient) and 0.88 kg waste from sterile wraps (0.88 kg CO_2e/patient). The LSC group produced 11.2 kg (11.2 kg CO_2e/patient) of solid waste, which existed of 6.03 kg consumable waste (6.03 kg CO_2e/patient), 3.35 kg single-use device waste (3.35 kg CO_2e/patient), 1.60 kg infection control waste (1.60 kg CO_2e/patient) and 0.99 kg waste from sterile wraps (0.99 kg CO_2e/patient). The LAP group produced 8.3 kg (8.3 kg CO_2e/patient) of solid waste, which existed of 5.86 kg consumable waste (5.86 kg CO_2e/patient), 0.82	for equipment is highest in the LSC group. The biggest contributors in waste in the RA-LSC group are consumables and infection control waste, in the LSC group consumables and single-use devices and in the LAP group consumables. Energy use adds more to the CO_2 footprint than waste.	Emissions for transport, manufacturing and disposal of instruments and goods and emissions based on preoperative and postoperative stay (length of stay) were not taken into account.

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			RA-LSC Age (years): 63.0 BMI (kg/m^2): 36.2 Prior abdominal surgery (%): 56 Uterine weight (g) 205.1 LSC Age (years): 60.3 BMI (kg/m^2): 31.5 Prior abdominal surgery (%): 52 Uterine weight (g) 166.31 LAP Age (years): 62.7 BMI (kg/m^2): 35.5 Prior abdominal surgery (%): 60 Uterine weight (g) 495.47		kg single-use device waste (0.82 kg CO_2e/patient), 1.60 kg infection control waste (1.60 kg CO_2e/patient) and 0.44 kg waste from sterile wraps (0.44 kg CO_2e/patient). The solid waste production of RA-LSC represented a 74% increase over LAP and a 36% increase over LSC. 3. Acidification No results in this study. 4. Eutrophication No results in this study. 5. Human Toxicity No results in this study. 6. Ecotoxicity No results in this study. 7. Ozone Depletion No results in this study.		
Thiel (2015)	Environmental Science & Technology Journal information ES&T is an impactful environmental science and technology research journal that aims to be transformational and direction-setting, publishing rigorous and robust papers for a multidisciplinary and diverse audience of scientists, policy makers and the broad	Type of study: LCA Objective: To assess the environmental impacts of four different surgical approaches to hysterectomy: vaginal, abdominal, laparoscopic, and robotic LCA-method: Hybrid LCA (ISO 14040-44) Setting and country: Hospital in the US	Goal and scope[1]: Quantitate the environmental emissions of a vaginal, an abdominal, a laparoscopic, and a robotic hysterectomy. Functional unit(s)[2]: One hysterectomy System boundaries: Operating theatre door to door (intraoperative period) Included stages:	This research used a hybrid LCA framework, by incorporating process LCA data and Economic Input Output LCA (EIO-LCA) data. Monte Carlo simulations were used to quantify the variability and uncertainty in emissions for each component of a hysterectomy. Waste audits were conducted from the surgeries of patients that underwent an abdominal, a laparoscopic or a robotic hysterectomy for	1. Climate change This study reported a difference in greenhouse gas (GHG) emissions between the four approaches for a hysterectomy. Robotic hysterectomies have the highest impact (100%) in greenhouse gas emissions, followed by the laparoscopic (65-70%), abdominal (35-40%) and vaginal approach (30-35%). The laparoscopic approach resulted in 30-35% less contribution to GHG emissions than a robotic approach, abdominal and	This life cycle assessment shows the biggest environmental impact is attributable to the robotic and laparoscopic surgical approaches for a hysterectomy. Within these modalities, the use of single-use instruments, single-use materials (gowns, gloves, etc.) and anesthetic gases are the biggest contributors.	Authors conclusion The trend is towards MIS that drives up the amount of pollution generated within the OR. Limitations The environmental impact of postoperative stay was not taken into account.

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	environmental community. Critical review: Peer reviewed article.	Facility: Magee-Womens Hospital of the University of Pittsburgh Medical Center, Pittsburgh, PA, USA Years of data collection: 2011 Surgical discipline(s): Obstetrics & gynecology Funding and conflict of interest: Financial support for the data collection came from Grant Number ULI RR024153 from the National Center for Research Resources (NCRR), a component of the National Institutes of Health (NIH), and NIH Roadmap for Medical Research. Support for graduate researchers came from Award No. 050434 from the National Science Foundation (NSF) Integrative Education and Research Traineeship (IGERT). The authors declare no competing financial interest.	Production, transport, energy use, pharmaceuticals, reuse, disposal/waste Stated excluded components: Infrastructure including machines and building; chemical manufacturing and cleaning products; hot water Inventory database: USLCI, EcoInvent Allocation: Impacts of reusable materials and equipment were apportioned based on estimated lifespan/number of uses. Normalization & Weighting: No Impacts reported: Yes (graphically) Contribution analysis: Yes Scenario analysis: No Comparative analysis: Yes Sensitivity analysis: No Uncertainty analysis:	noncancer related reasons. For the course of 1 year, waste from 62 cases of each type of hysterectomy were quantified and characterized (15 abdominal, vaginal and robotic, 17 laparoscopic). Materials were matched with the most relevant unit process within either USLCI and EcoInvent. For complex items of medical equipment an economic input-output approach was taken (i.e. based on the price paid for each item). Patient records were used to calculate both pathogenic waste (uterine weight) and quantities of anesthesia and abdominal insufflation. Transportation impacts were calculated based on distances between facilities, according to waste hauling data from the relevant facility. Impacts of resuable materials and equipment were based on estimated lifespan/number of uses. Data on the sterilization process for reusable materials and linens was sourced from the literature. Characterization methods:	vaginal approaches in between 60-70% less contribution in comparison to the robotic approach. Biggest contributors were: the use of anaesthetic gases (in all surgical modalities) and single-use surgical instruments (for laparoscopic and robotic approach). 2. Waste The robotic approach for a hysterectomy produced the highest amount of waste, following the laparoscopic, abdominal and vaginal approaches. Robotic hysterectomies produced 13.7 kg municipal solid waste (MSW) per case, which resulted in a total of 30% more waste compared to the average of the other approaches. This consisted of 22% by weight by gowns, drapes and bluewrap (SMS PP), 50% gloves and other plastics, 18% paper and 5% cotton. Abdominal hysterectomies had an average of 9.2 kg of MSW production and produced the largest amount of cotton waste (blue towels, laparotomy pads) at 1 kg per average surgery (11% of the MSW by weight). Across all four surgeries, SMS PP material were the majority of the MSW by weight, from 22% of the weight of a robotic		

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			Yes (Monte Carlo) Variance analysis: No	Impacts were calculated using TRACI 2.1 for both process LCA and EIO-LCA. Embodied energy was calculated using cumulative energy demand (CED) version 1.08 developed by EcoInvent version 2.0 and PRé Consultants for process LCA and the energy analysis function found on the EIO-LCA tool.	hysterectomy and 35% for a laparoscopic hysterectomy. Other types of plastics, from thin film packaging wrappers to hard plastic trays, made up a minimum of 36% of the total MSW weight for vaginal hysterectomies and a maximum of 46% for robotic hysterectomies. 3. Acidification The robotic approach had the highest impact on acidification (100%), followed by the laparoscopic (70-75%), abdominal (25%) and lastly the vaginal approach (20%). The big difference between the robotic and laparoscopic approach in comparison to the vaginal and abdominal approach can be attributed to the use of single-use surgical instruments. 4. Eutrophication The robotic approach had the highest impact on eutrophication (100%), followed by the laparoscopic (70-75%), abdominal (60-65%) and lastly the vaginal approach (55%). MSW, single-use surgical instruments and single-use materials are the biggest contributors. 5. Human Toxicity		

Study reference	Journal	Study characteristics	Methods	Data collection	Outcomes	Interpretation	Comments
					The impact was divided into two subcategories: carcinogenic and non-carcinogenic potential. The robotic approach had the highest impact in both Nocarcinogenic and non-carcinogenic potential categories (100%). The carcinogenic and non-carcinogenic impact of the laparoscopic approach resulted in respectively 80% and 85-90%. For the abdominal approach 90-100% and 80-90% and for the vaginal approach 80% and 70-75%. Single-use materials contributed most in all surgical modalities. 6. Ecotoxicity The robotic approach had the highest impact on ecotoxicity (100%), followed by the laparoscopic (90-95%), abdominal (90%) and lastly the vaginal approach (75%). Single-use materials contributed most in all surgical modalities. 7. Ozone Depletion The robotic approach had the highest impact on ozone depletion (100%), followed by the laparoscopic (60-65%), abdominal and the vaginal approach (0-5%).		

Study reference	Journal	Study characteristics	Methods	Data collection	Outcomes	Interpretation	Comments
					The use of single-use surgical instruments contributed most.		

[1]Goals and scope: 'Phase of life cycle assessment in which the aim of the study, and in relation to that, the breadth and depth of the study is established'

[2]Functional unit: Quantified description of the function of a product or process that serves as the reference basis for all calculations regarding impact assessment.