Four LCAs in an Afternoon!

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Anaesthesia and Intensive Care,
Western Health, Melbourne

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The Four Studies this Afternoon

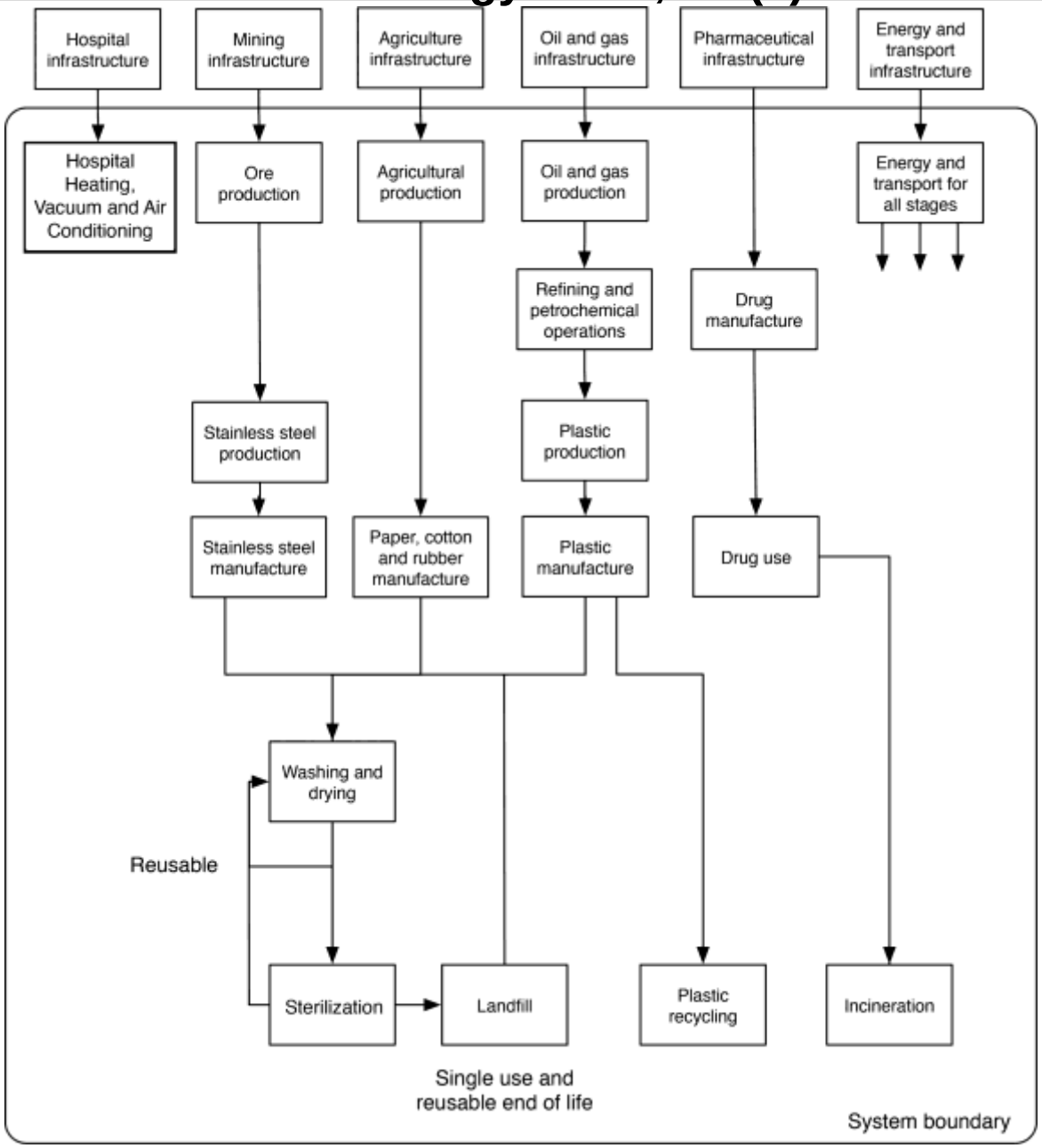
1. Thiel CL. Environmental impacts of surgical procedures: life cycle assessment of hysterectomy in the United States (2014)
2. McGain F. Financial and environmental costs of reusable and single-use anaesthetic equipment (2017)
3. Zhang D. The Environmental Impact of Open Versus Endoscopic Carpal Tunnel Release (2022)
4. Tan E. Carbon footprint of dermatologic surgery (2021)

- **With moderation and accompanying slide show information**
- **A creative, conjecturing, and critical mind is vital (as always!)**

From: C Footprint of General, Regional, Combined Anesth for TKRs

Anesthesiology. 2021;135(6):976-991

The System Boundary



Copper	11.9 kg CO_2e/ kg
Cotton	27.2 kg CO_2e/ kg
Glass	3.6 kg CO_2e/ kg
Plastics-non PVC	3.3 kg CO_2e/ kg
Plastics -non PVC- recycled	1.8 kg CO_2e/ kg
Plastics- PVC	2.6 kg CO_2e/ kg
Plastics- PVC – recycled	1.1 kg CO_2e/ kg
Rubber- synthetic and natural	2.0 kg CO_2e/ kg
Stainless steel	6.8 kg CO_2e/ kg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Environmental Science & Technology

2015, 49: 1779−1786

Environmental Impacts of Surgical Procedures: Life Cycle Assessment of Hysterectomy in the United States

Cassandra L. Thiel,*[,†,⊗] Matthew Eckelman,[§,⊗] Richard Guido,[‡,⊗] Matthew Huddleston,[†,⊗] Amy E. Landis,[⊥,⊗] Jodi Sherman,[∥,⊗] Scott O. Shrake,[⊥,⊗] Noe Copley-Woods,[‡,⊗] and Melissa M. Bilec[†,⊗]

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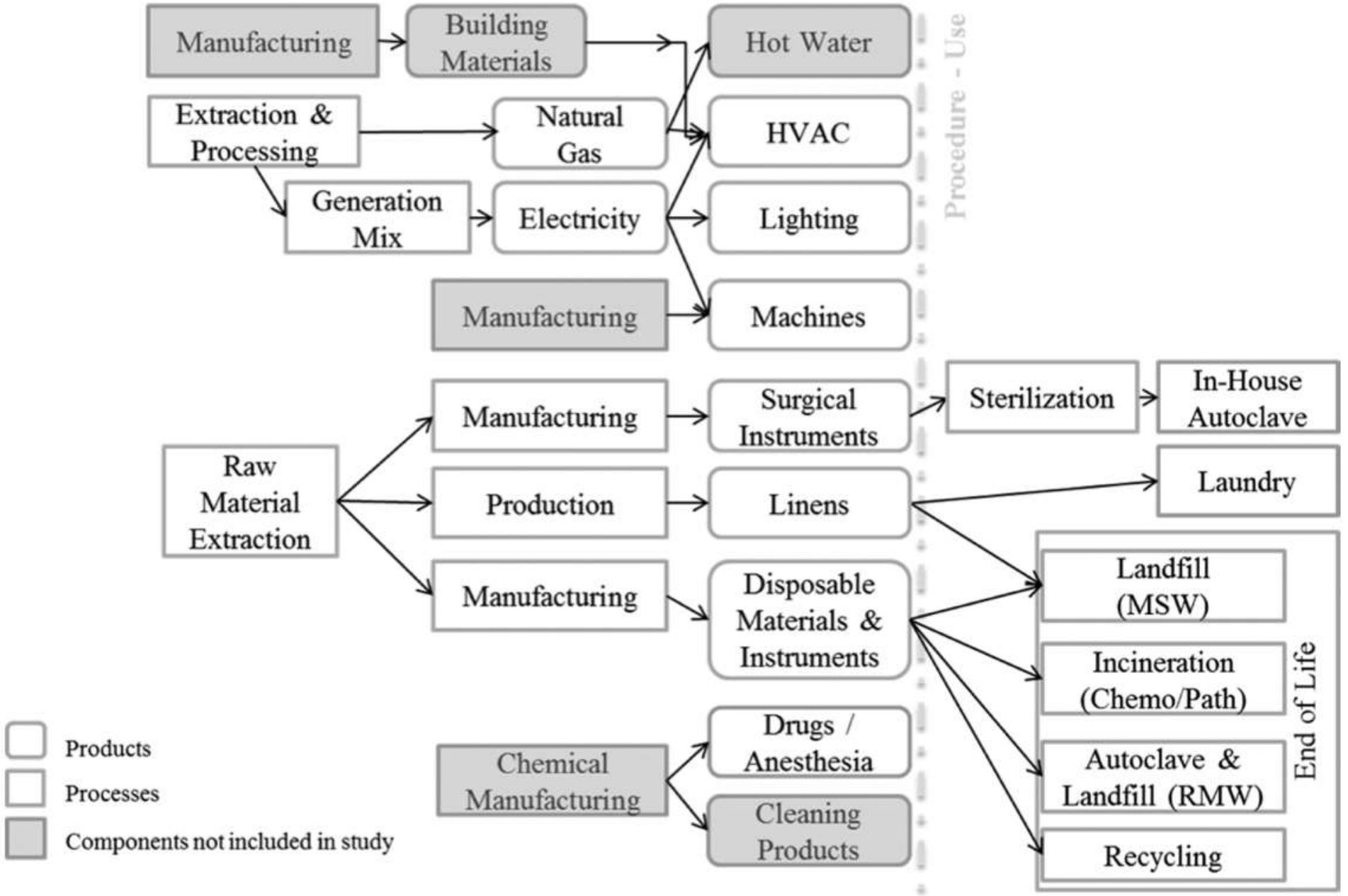
Hysterectomy: Methods I

1. Thiel et al, Magee Women's Hospital, Pittsburgh
2. Goal and Scope: To compare the carbon footprint of one hysterectomy: vaginal, abdominal, laparoscopic, robotic
3. Included Anaesthesia
4. "Limited information on the environmental impacts of the sterilization process for reusable materials. …sterilization of surgical trays was based off an energy consumption estimate (2.6 kWh per stainless steel surgical instrument tray) of the autoclaving machines at Magee."
5. Monte Carlo analyses…


Manufacturing
Building Materials
Hot Water
Extraction & Processing
Natural Gas
HVAC
Generation Mix
Electricity
Lighting
Manufacturing
Machines
Procedure - Use
Raw Material Extraction
Manufacturing
Surgical Instruments
Sterilization
In-House Autoclave
Production
Linens
Laundry
Manufacturing
Disposable Materials & Instruments
Landfill (MSW)
Incineration (Chemo/Path)
Autoclave & Landfill (RMW)
Recycling
End of Life
Chemical Manufacturing
Drugs / Anesthesia
Cleaning Products
Products
Processes
Components not included in study

Hysterectomy: Methods II

1. Prospective single centre study (consent required) of waste audits of 62 cases
2. Municipal Solid Waste (MSW) vs. (autoclaved) Regulated Medical Waste (RMW)
3. Life Cycle Inventories (USLCI, ecoinvent)
4. **Hybrid Approach:** ***EEIO analyses of complex and expensive lap. and robotic equipment***

Table 1: Life Cycle Inventory Databases and Processes Chosen for Hysterectomy Materials found in MSW

Material Type	LCI Database	Production Process Name	LCI Database	Disposal Process Name
Cotton	ecoinvent unit process	Textile, woven cotton, at plant/GLO U	ecoinvent unit process	Disposal, inert material, 0% water, to sanitary landfill/CH U
PVC	ecoinvent unit process	Polyvinylchloride, at regional storage/RER U	ecoinvent unit process	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U
HDPE	ecoinvent unit process	Polyethylene, HDPE, granulate, at plant/RER U	ecoinvent unit process	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U
LDPE	ecoinvent unit process	Polyethylene, LDPE, granulate, at plant/RER U	ecoinvent unit process	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U
Glass	ecoinvent unit process	Packaging glass, white, at plant/RER U	ecoinvent unit process	Disposal, glass, 0% water, to inert material landfill/CH U
Wood	USLCI	Plywood, at plywood plant, US SE/kg/US	ecoinvent unit process	Process-specific burdens, sanitary landfill/CH U
Complex Instruments (Sharps)	EIO-LCA	Sector # 339112: Surgical and Medical Instrument Manufacturing	EIO-LCA	Sector #562000: Waste management and remediation services

Table 3: Average Weight and Estimated Lifespan of Reusable Surgical Linens

Cotton Material	Weight (kg)	Lifespan (# Uses)
Sheet	0.292	50
Blanket	0.698	52
Pillowcase	0.098	32
Blue Towel	0.054	10
Under-Patient Chuck	0.51	42
Gown	0.344	48

- The USLCI electricity process was modified to match the energy mix of Pennsylvania for 2012 which is 73% coal, 22% nuclear, 3% natural gas…

EE-IO LCA for Single Use Complex Instruments

- **Economic Input-Output LCA Setup** and LCIA Monetary values for EIO-LCA were evaluated **using the purchaser price** and assigned background emissions using the corresponding sectors within the North American Industry Classification System

- For the production of disposable complex medical devices, NAICS sector 339112 **Surgical and Medical Instrument Manufacturing was selected**

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Table 6: Impact Category Characterization and Conversion for EIO-LCA and Process LCA

Impact Category	EIO-LCA Units	Process LCA Units (TRACI)	EIO-LCA Impacts per $1US2002 Purchaser	CF (TRACI)	EIO-LCA Impacts per $1US2002 Purchaser (Converted)
Ozone depletion	kg CFC-11e	kg CFC-11 eq	0.000002	1	0.000002
Global warming	kg CO2e	kg CO2 eq	0.403317	1	0.403317
Smog	kg O3e	kg O3 eq	0.000002	1	0.000002
Acidification	kg SO2e	mol H+ eq	0.002117	50.79	0.10752243
Eutrophication	kg Ne	kg N eq	0.000068	1	0.000068
Carcinogenics	kg benzene eq	CTUh	0.000037	2.97E-07	1.0989E-11
Non carcinogenics	kg toluene eq	CTUh	0.023076	5.3E-08	1.22303E-09
Respiratory effects	kg PM10e	kg PM10 eq	0.000698	1	0.000698
Ecotoxicity	kg 2,4D	CTUe	0.000018	860	0.01548
Energy	MJ	MJ	5.87	1	5.87

62 Hysterectomies: Waste

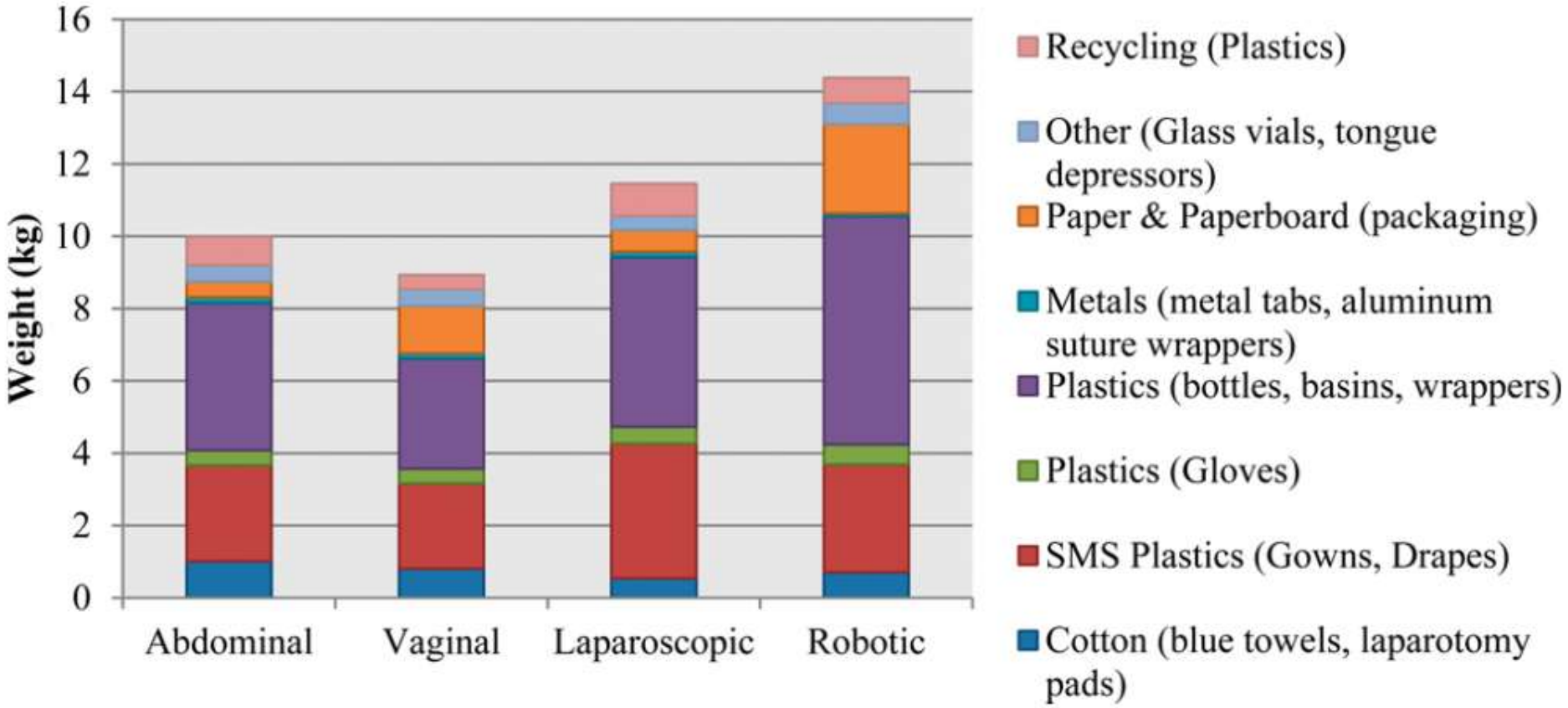
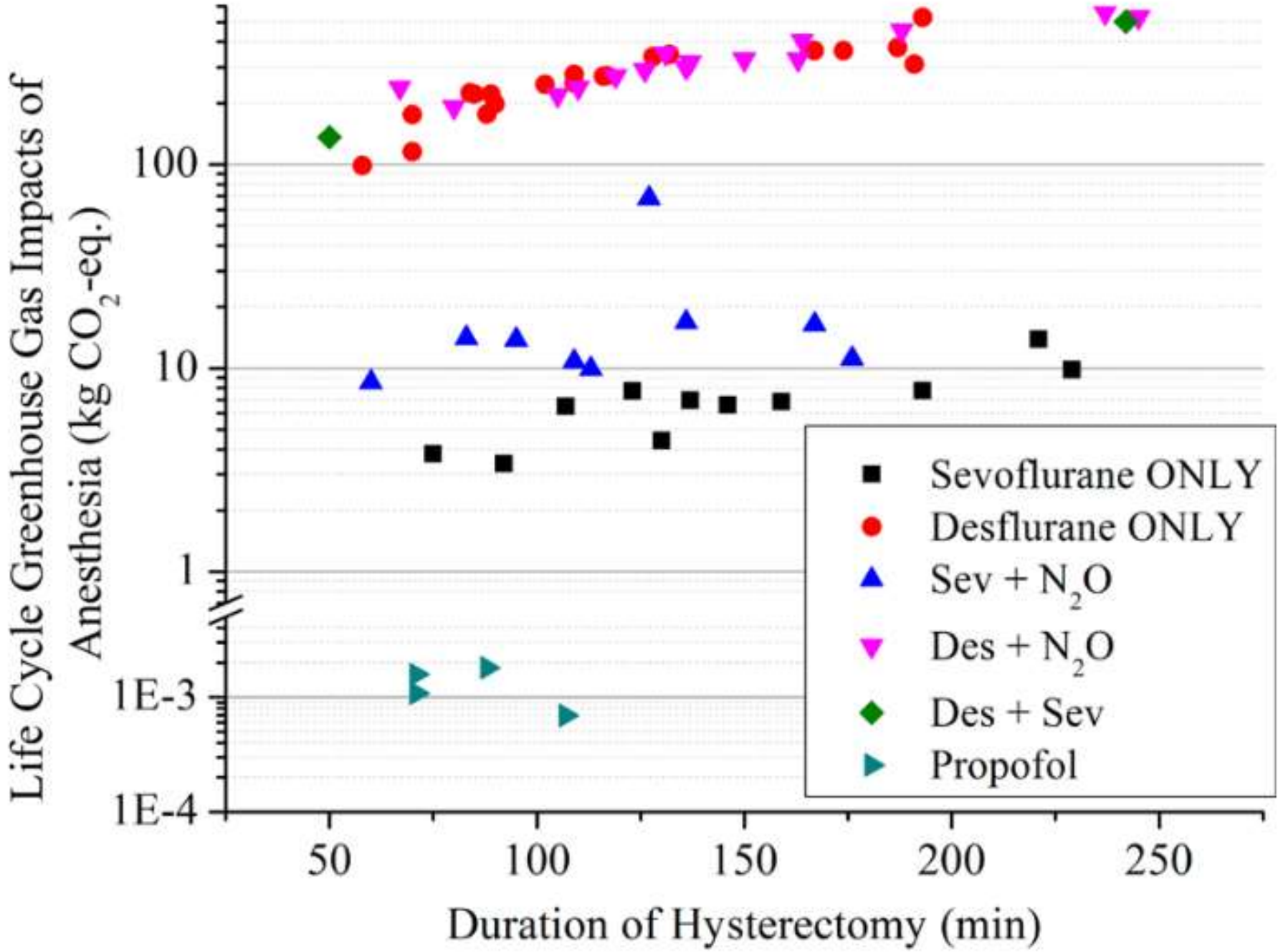
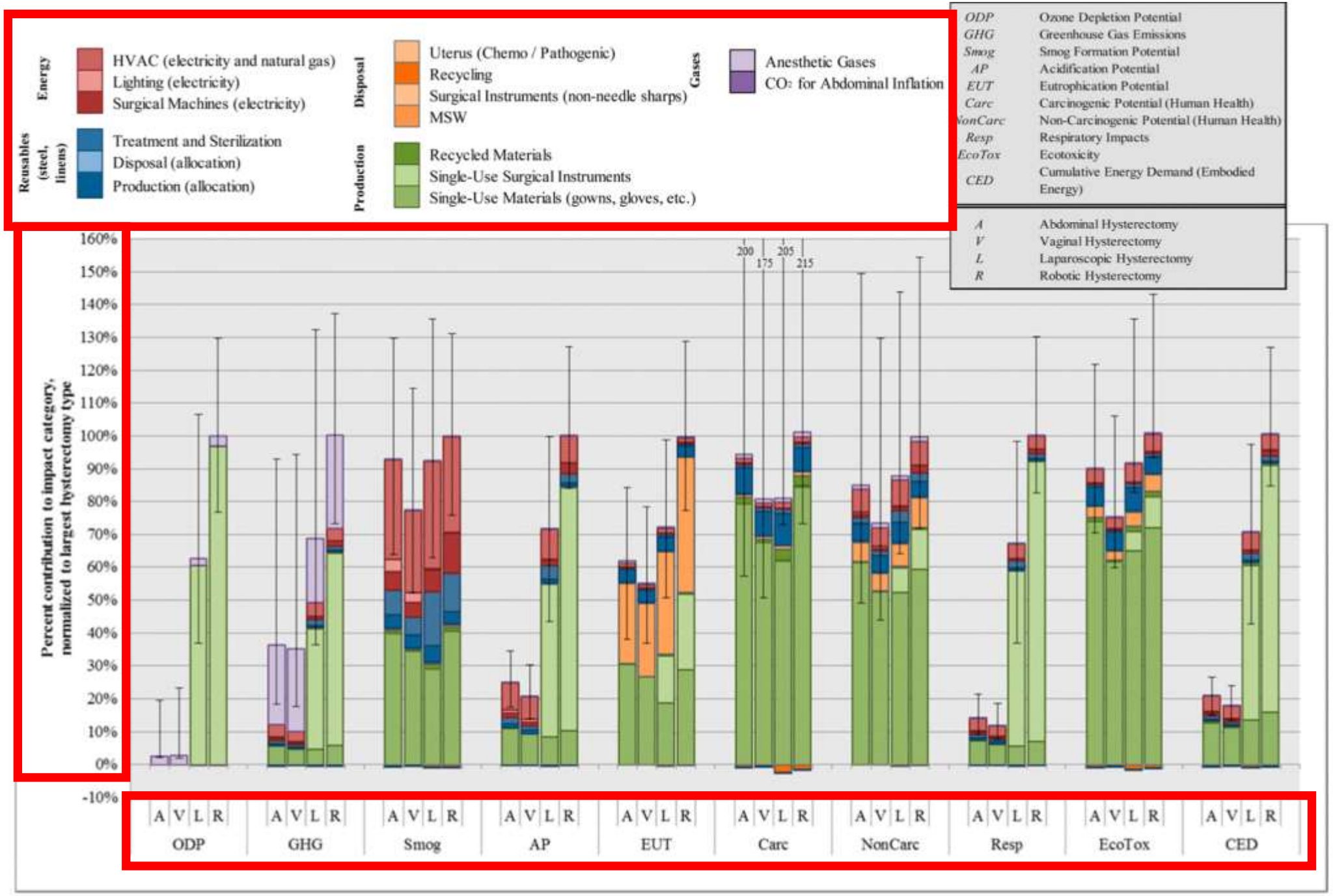


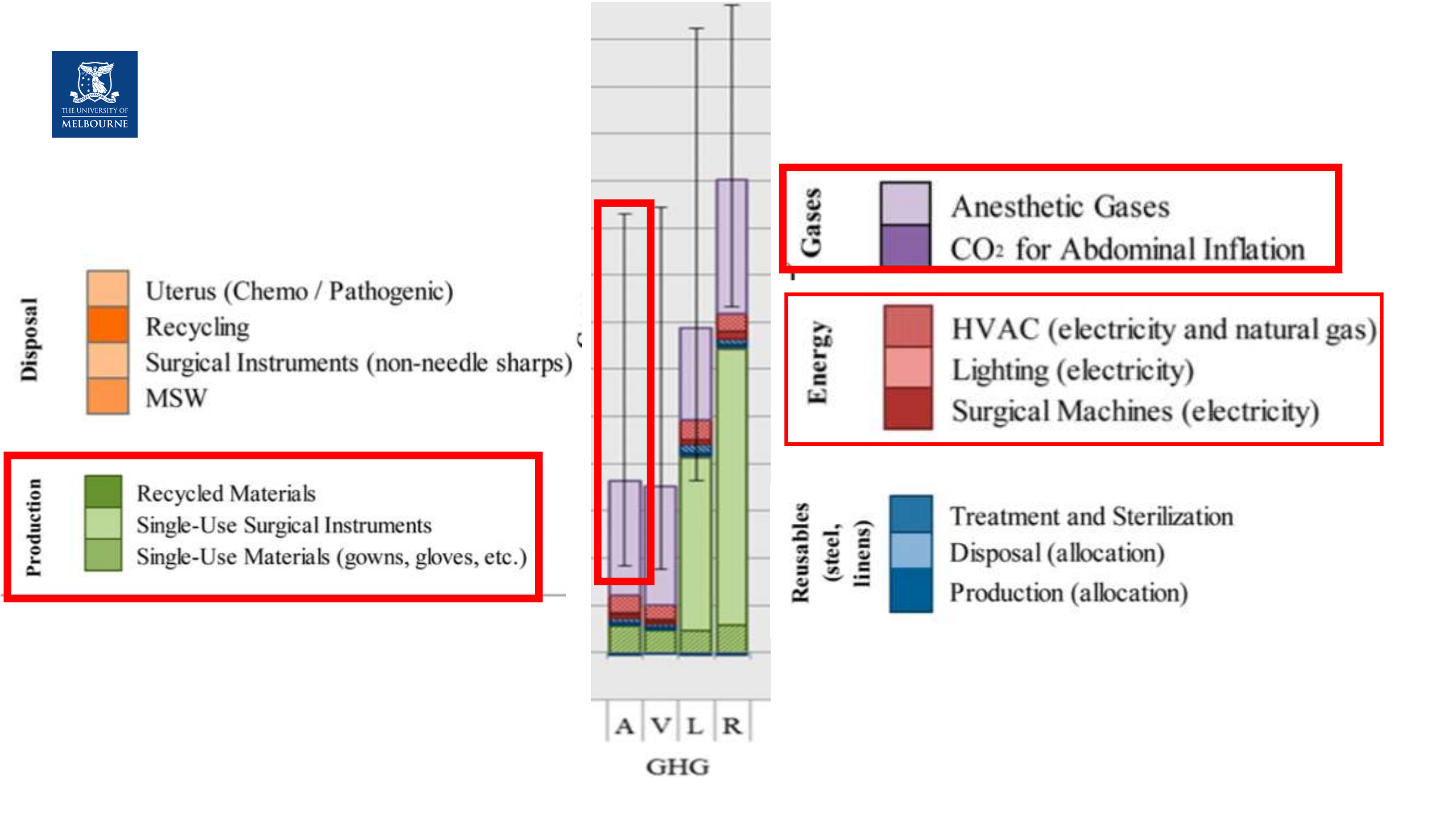
Figure 2. Average material composition of nonhazardous solid waste (municipal solid waste and recycling) from a single hysterectomy by surgery type. SMS = spunbond-meltblown-spunbond.

Recycling: 4-8% Total


Life Cycle Greenhouse Gas Impacts of Anesthesia (kg CO_2-eq.)
100
10
1
1E-3
1E-4
50
100
150
200
250
Duration of Hysterectomy (min)
Sevoflurane ONLY
Desflurane ONLY
Sev + N_2O
Des + N_2O
Des + Sev
Propofol

%?!


Energy
HVAC (electricity and natural gas)
Lighting (electricity)
Surgical Machines (electricity)
Reusables (steel, linens)
Treatment and Sterilization
Disposal (allocation)
Production (allocation)
Disposal
Uterus (Chemo / Pathogenic)
Recycling
Surgical Instruments (non-needle sharps)
MSW
Production
Recycled Materials
Single-Use Surgical Instruments
Single-Use Materials (gowns, gloves, etc.)
Gases
Anesthetic Gases
CO2 for Abdominal Inflation
ODP Ozone Depletion Potential
GHG Greenhouse Gas Emissions
Smog Smog Formation Potential
AP Acidification Potential
EUT Eutrophication Potential
Carc Carcinogenic Potential (Human Health)
NonCarc Non-Carcinogenic Potential (Human Health)
Resp Respiratory Impacts
EcoTox Ecotoxicity
CED Cumulative Energy Demand (Embodied Energy)
A Abdominal Hysterectomy
V Vaginal Hysterectomy
L Laparoscopic Hysterectomy
R Robotic Hysterectomy
Percent contribution to impact category, normalized to largest hysterectomy type
160%
150%
140%
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-10%
200
175
205
215
A V L R
ODP
GHG
Smog
AP
EUT
Carc
NonCarc
Resp
EcoTox
CED


Disposal
Uterus (Chemo / Pathogenic)
Recycling
Surgical Instruments (non-needle sharps)
MSW
Production
Recycled Materials
Single-Use Surgical Instruments
Single-Use Materials (gowns, gloves, etc.)
A
V
L
R
GHG
Gases
Anesthetic Gases
CO2 for Abdominal Inflation
Energy
HVAC (electricity and natural gas)
Lighting (electricity)
Surgical Machines (electricity)
Reusables (steel, linens)
Treatment and Sterilization
Disposal (allocation)
Production (allocation)

Hysterectomy: Results

1. 500,000 cases in the USA p.a. (A-40%, V-20%, Lap.-30%, R-10%)
2. 212,000 tonnes CO_2e p.a..
3. **= 420 kg CO_2e per hysterectomy**
4. Anaesthetics were important (i.v. vs. gas).
   - i.v. from <1kg CO_2e /case to…
   - Desflurane or N_2O: **500 kg CO_2e** /case (approx. 2L/min. for 4 hours)
5. Cotton: largest 'disposable' CO_2e footprint (though <5% b.w.)
6. Reusable instruments minor
7. Energy: HVAC (70%)>OR machines>Lighting=Sterilisation…(?!)
8. The Supplementary data don't clarify actual CO_2e emissions

Table 1. Components of Hysterectomy Contributing Significantly to Environmental Impacts and Potential Impact Reduction Strategies, A = Abdominal, V = Vaginal, L = Laparoscopic, R = Robotic, all = All Hysterectomy Types

Issue	*Environmental Impact Categories*	*% of Total Impacts in Categories*	*Potential Reduction Strategies*
Energy used to run HVAC (heating, ventilation, and air conditioning)	• Greenhouse Gas Emissions, • Smog Formation, • Acidification Potential, • Respiratory Impacts, • Cumulative Energy Demand	10-35% (A&V) 5-30% (L&R)	• Regular maintenance of mechanical equipment, • Upgrade mechanical equipment and filters, • Reduce energy leaks in ducts and joints, • Reduced ventilation rates when OR not-in-use, • Use more renewable energy sources
Anesthetic Gases	• Greenhouse Gas Emissions	30% (L&R) 70% (A&V)	• Install waste gas capturing technology in OR, • Apply lowest fresh gas flow rates, • Avoid desflurane and N_2O
Production of Disposable Cotton	• Carcinogens, • Non-Carcinogens, • Ecotoxicity • All other categories analyzed	25-60% (all) 15-40% (A&V)	• Reuse cotton, • Recycle cotton, • Use organic cotton, • Use other fibers (bamboo, hemp, etc.)
Production of Disposable Gowns, Drapes, and BlueWrap (SMS-PP)	• Non-Carcinogens, • Ecotoxicity, • Cumulative Energy Demand	10-30% (all)	• Recycle materials, • Replace with reusable materials
Disposal of PP (polypropylene)	• Eutrophication	10-20% (all)	• Recycle materials, • Replace with reusable materials
Production of Disposable Surgical Instruments	• Ozone Depletion Potential, • Greenhouse Gas Emissions, • Acidification Potential, • Eutrophication, • Respiratory Impacts, • Cumulative Energy Demand	20-99% (L&R)	• Encourage environmental manufacturing, • Utilize reusable instruments, • Utilize third-party reprocessing

Hysterectomy: Discussion

1. Clearly a study that required much effort, collaboration, and thought!
2. Choice of anaesthesia vital
3. Single use cotton is anathema to a low carbon world!
4. Supplementary data don't clarify CO_2e etc. figures: numerical data?
5. Sterilisation and HVAC data?
6. Beware the Hybrid Study (inflation of the CO_2e for laparoscopic and robotic cases)

Financial and environmental costs of reusable and single-use anaesthetic equipment

F. McGain[1,2,*], D. Story[3], T. Lim[1] and S. McAlister[4]

BJA, 118 (6): 862–9 (2017)

Circuits, Handles, Blades, Face Masks

Anaesthetic Equipment : Methods I

1. McGain et al, Melbourne, 2015 (2017 published)
2. Goal and Scope (and Functional Unit): "To estimate the financial and environmental costs for a small hospital to switch from single-use to reusable airway equipment"
3. System Boundary
4. Consequential LCAs indicate what's occurring in the broader economy
   - the CO_2e emissions stemming from electricity used to process more reusable anaesthetic equipment were not an average of CO_2e emissions for electricity generation in Australia, but those arising from the marginal electricity supplier
   - *Each new kilowatt hour of electricity during the next 5–10yr in Australia will most probably be sourced from coal*

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Tony Abbott: records

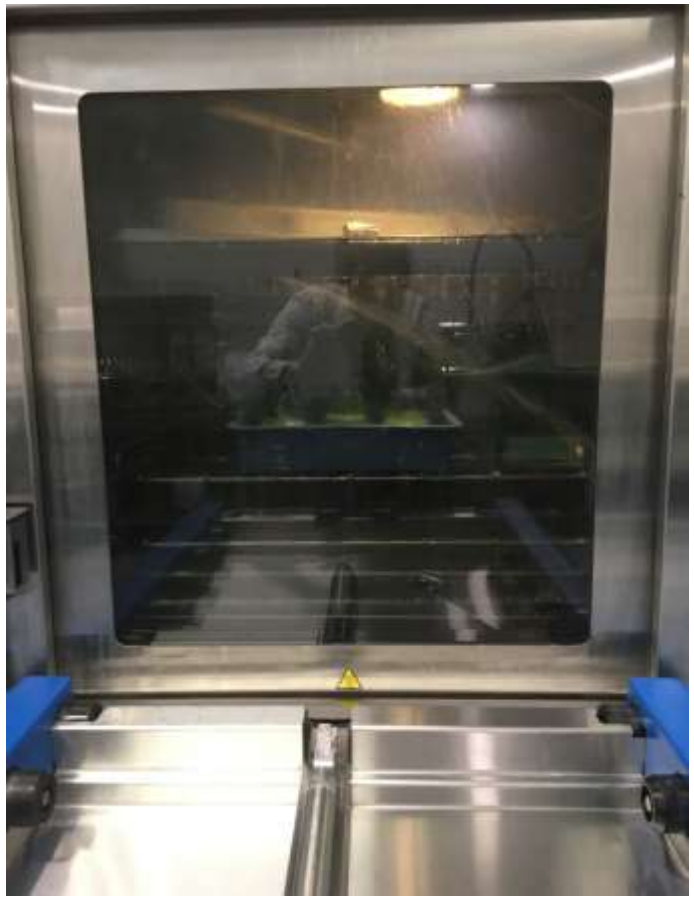
This page provides information about records for Anthony John (Tony) Abbott held by the National Archives.

Tony Abbott was the Prime Minister of Australia from 2013 to 2015.

Behind the Scenes in LCA Studies...

Holding trays for the washer

The washer in action



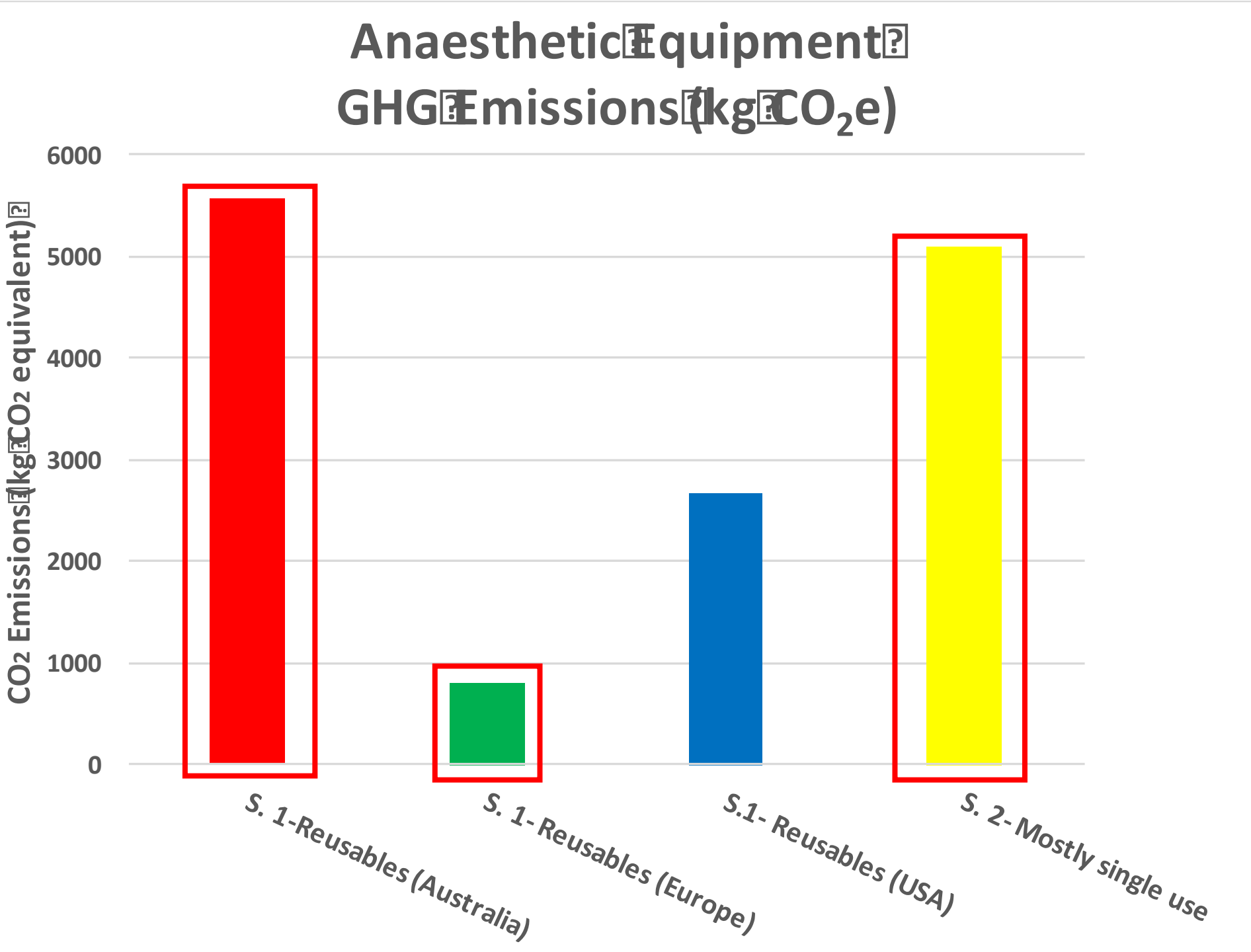
A steriliser load

Steriliser Electricity Consumption

Scenarios for replacing reusable anaesthetic equipment with disposable/single use items.	Washer and dryer loads p.a.	Steam steriliser use p.a.	Hydrogen peroxide (H_2O_2) steriliser use p.a.
1. **All reusable anaesthetic items. Current practice at Footscray Hospital.**	550 loads	4,490 reusable direct laryngoscope blades and 630 LMAs	Reusable video-laryngoscopes 180 cycles
2. **Convert to disposable anaesthetic items except for reusable handles for the direct laryngoscopes (Austin Hospital)**	0 loads	0 cycles	0 cycles
3. **All single use anaesthetic equipment (including single use direct laryngoscope handles).**	0 loads	0 cycles	0 cycles
4. **Replace only reusable face masks with single use face masks.**	365 loads	4,490 reusable direct laryngoscope blades and 630 LMAs	180 cycles
5. **Replace only direct laryngoscope reusable blades with single use blades.**	550 loads	630 LMAs	180 cycles

Table 3 Summed financial costs (in AUD$) for anaesthetic equipment for Scenario 1 (reusables) and Scenario 2 (mainly single use) in 2015. CSSD, Central Sterile and Supply Department; LMAs, laryngeal mask airways

Process/device	All reusable equipment (Scenario 1)	All disposable or single-use equipment except for reusable direct laryngoscope handles and videolaryngoscopes (Scenario 2)
Labour in CSSD	$14 560	$0
Washer loads	$1595	$290
Steam sterilization	$815	$0
H_2O_2 sterilization cycles	$4356	$0
Circuits and bags	$2292	$3850
Face masks	$2482	$19 800
LMAs	$8500	$13 230
Direct laryngoscope blades	$1460	$19 350
Direct laryngoscope blades' wrappings	$180	$0
Direct laryngoscope handles	$470	$470
Videolaryngoscope blades	$0	$11 500
Videolaryngoscope handles	$0	$0
Videolaryngoscope blades' packaging	$250	$250
Waste costs (general waste at $0.25 kg^{-1})	$25	$278
Total	$36 985	$69 018


Anaesthetic Equipment GHG Emissions (kg CO_2e)
CO_2 Emissions (kg CO_2 equivalent)
6000
5000
4000
3000
2000
1000
0
S. 1-Reusables (Australia)
S. 1- Reusables (Europe)
S.1- Reusables (USA)
S. 2- Mostly single use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3. Carpal Tunnel Release

SCIENTIFIC ARTICLE

The Environmental Impact of Open Versus Endoscopic Carpal Tunnel Release

Dafang Zhang, MD,*† George S. M. Dyer, MD,*† Philip Blazar, MD,*† Brandon E. Earp, MD*†

J Hand Surg Am. 2023 Jan;48(1):46-52

Carpal Tunnel Release: Methods

1. Dept. of Orthopedic Surgery, Brig. and Women's, Boston
2. **Retrospectively** reviewed: 14 open and 14 endoscopic CTRs
3. CTR with an Anesthesiologist present
4. Average surgical time= 38 minutes or 49 minutes
5. Goal and Scope: To compare the carbon footprint of oCTR vs. eCTR from start to finish in the OR only
6. Process Diagram?
7. Anaesthesia?

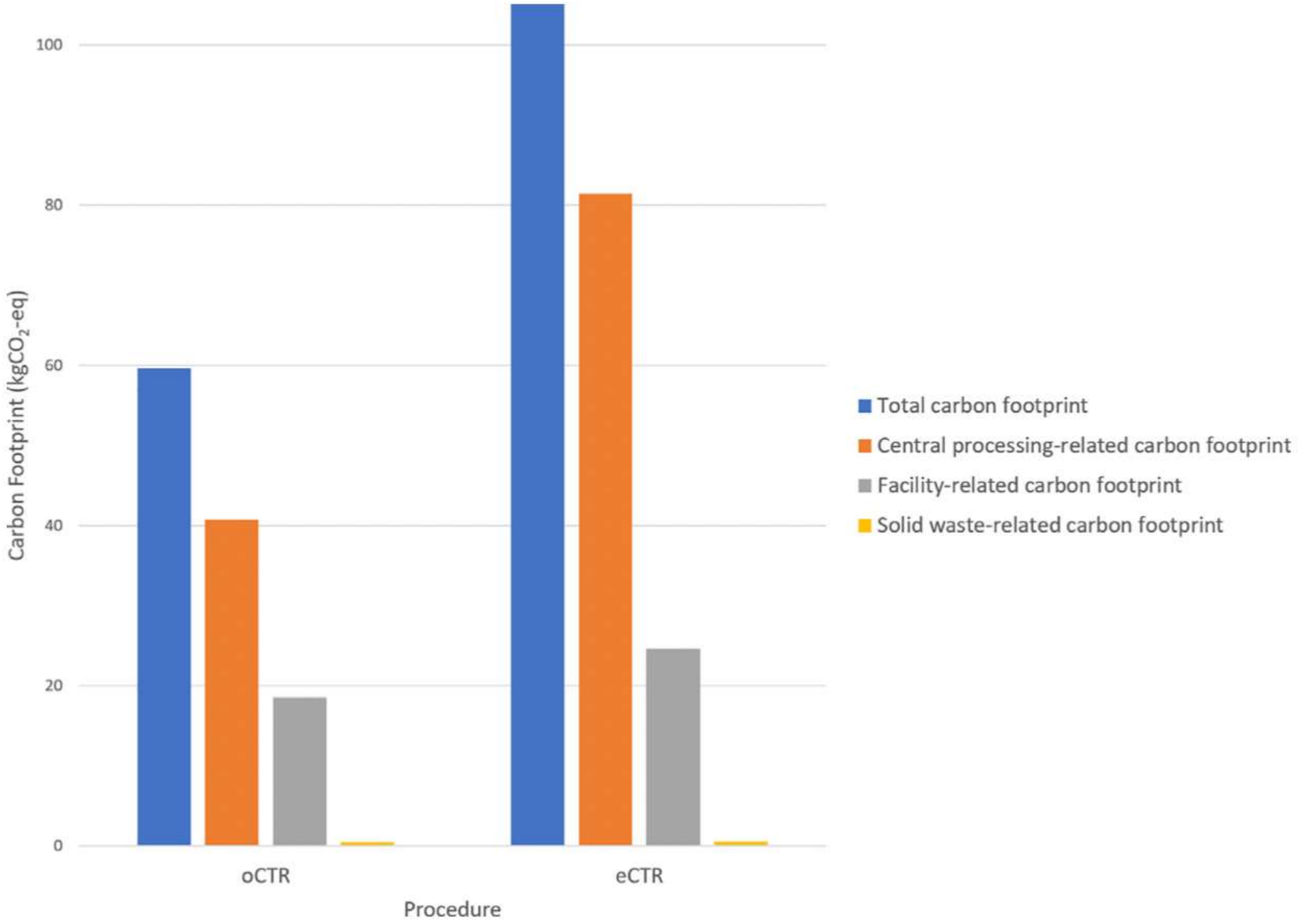
Carpal Tunnel Release: Results

1. Energy

- 14.4 kWh for OR lights (half hour operation)…
- 14.4 kWh for Anesthesia equipment…
- 9.6 kWh for HVAC…
- **864 kWh for 1 sterilization cycle**… **(we found around 20 kWh/cycle)**
- 1 kWh = 0.707 kg CO_2e emissions (US EPA electricity grid)

2. **Waste** (minor)
- 1.9- 2.5 kg solid waste (0.2 kg CO_2e/kg waste: UK landfill waste)

3. **TOTAL= 83 kg CO_2e emissions (vs. 400 kg for a hysterectomy)**


100
80
60
40
20
0
Carbon Footprint (kgCO2-eq)
oCTR
eCTR
Procedure
Total carbon footprint
Central processing-related carbon footprint
Facility-related carbon footprint
Solid waste-related carbon footprint

Carpal Tunnel Release: Discussion

1. **Variability in the carbon footprint of surgical procedures**
- **From 6 to 814 kg CO_2e (Rizan, Ann. Surg., 2020)**
- Various boundaries for LCAs…
2. **Waste** (minor)
- 1.9- 2.5 kg solid waste (0.2 kg CO_2e/kg waste: UK landfill waste)
3. **TOTAL= 83 kg CO_2e emissions**
4. **No procurement nor anaesthesia CO_2e emissions…**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4. Skin Lesion Surgery

Australasian Journal of Dermatology

Australasian Journal of Dermatology (2021) 62, e170–e177 doi: 10.1111/ajd.13522

REVIEW ARTICLE

Carbon footprint of dermatologic surgery

Eugene Tan[1] | **David Lim**[2]

[1]*Western Skin Institute, St. Albans, Victoria, Australia, and* [2]*Skin Institute, Auckland, New Zealand*

Dermatologic Surgery: Methods

- **LCA Goal and Scope, Inventory Analysis, Interpretation**

1. To undertake a process based attributional LCA of the carbon footprint of a skin cancer operation in Melbourne, Australia
   - Using OpenLCA, Evah database etc.
2. Cradle to Grave
3. **Functional Unit?**
   - One skin cancer in a single admission to a private practice/hospital
4. **System Boundary?** (what does one require for an operation?)

Dermatologic Surgery: Methods

1. Discussion of Input Output vs. Process based LCAs
   - "A key limitation of process based is truncation errors"…
2. **Transportation**
   - At all?
   - Metro. Vs Rural transport
   - Waste transportation
   - Sources of information?
3. **Functional Unit?**
   - Removal of one skin cancer in a single admission to a private practice (with a 'comparison' to a public hospital)


(a)


(c)


(b)


(d)

Australian National Greenhouse Accounts Factors

For individuals and organisations estimating greenhouse gas emissions

February 2023

Item (Equipment, Gases, Energy)	Carbon Dioxide Equivalent Emissions per Kilogram, Item, Milliliter, or Liter
Average anesthesia duration	
Electricity directly associated with anesthesia (Victorian electricity = 1.12 kg carbon dioxide equivalent	
Patient air warmer (3M, USA) 0.8 kilowatt-hours/h (product information) = 0.9 kg carbon dioxide equivalent emissions/h use	

Perioperative Medicine | December 2021

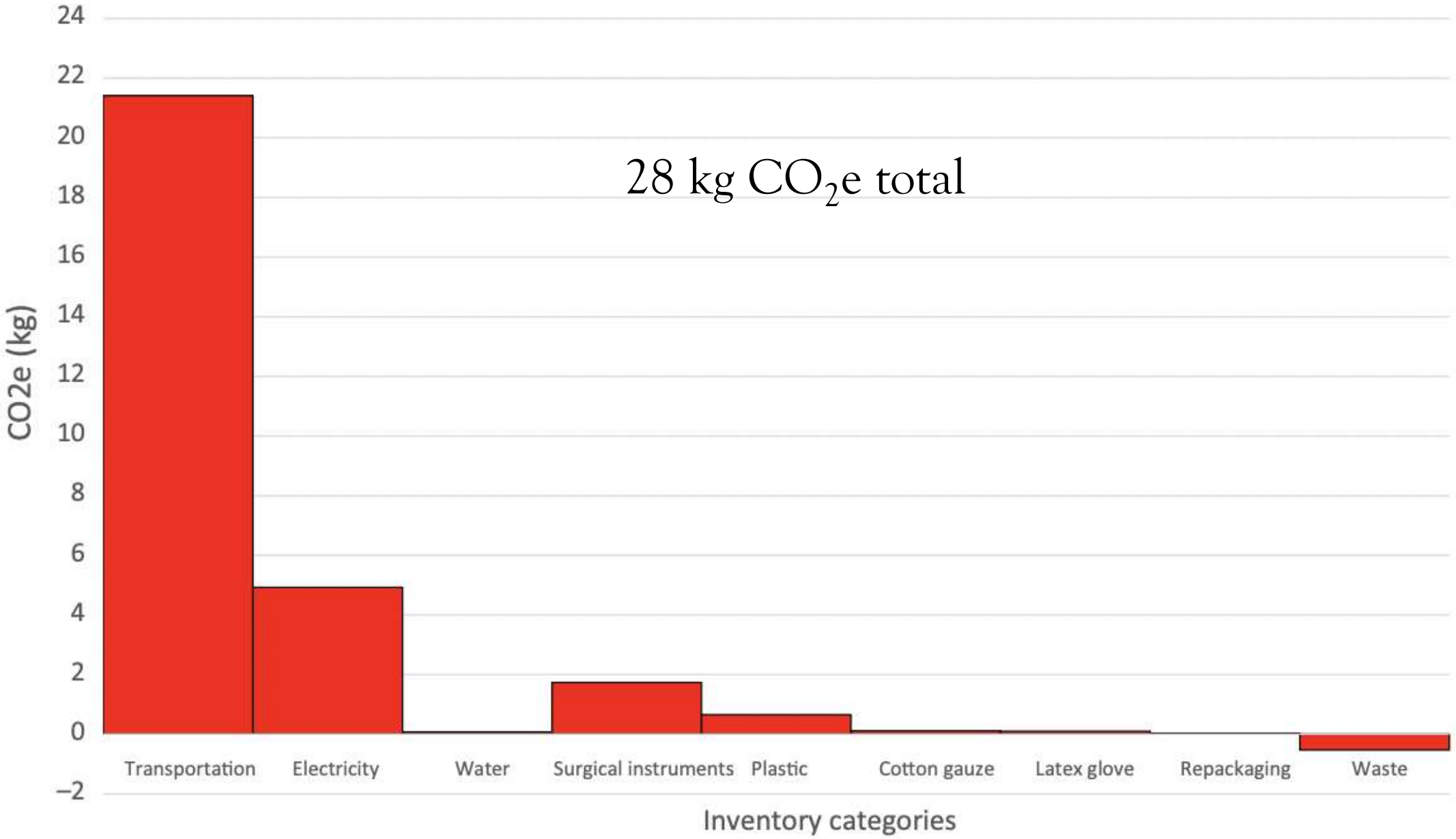
Carbon Footprint of General, Regional, and Combined Anesthesia for Total Knee Replacements

Forbes McGain, F.A.N.Z.C.A, F.C.I.C.M., Ph.D.; Nicole Sheridan, F.A.N.Z.C.A.; Kasun Wickramarachchi, B.Sc., M.P.H., M.D.; Simon Yates, M.D.; Brandon Chan, M.B.B.S.; Scott McAlister, B.Sc., P.grad., Dip.Sci., M.Eng.Sci.

+ Author and Article Information

Anesthesiology December 2021, Vol. 135, 976–991.

Plastics, polyvinyl chloride recycled	1.1 kg carbon dioxide equivalent emissions/kg
Rubber, synthetic and natural	2.0 kg carbon dioxide equivalent emissions/kg
Stainless steel	6.8 kg carbon dioxide equivalent emissions/kg
Gases	
Oxygen	0.0021 kg carbon dioxide equivalent emissions/l
Compressed air	0.00051 kg carbon dioxide equivalent emissions/l
Sevoflurane global warming potential = 130)[11]	0.196 kg carbon dioxide equivalent emissions/ml liquid


28 kg CO_2e total
CO2e (kg)
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
Transportation
Electricity
Water
Surgical instruments
Plastic
Cotton gauze
Latex glove
Repackaging
Waste
Inventory categories

Dermatologic Surgery: Results I

1. Transport

- Staff and patient transport
- Data sources?
- 21kg CO_2e emissions
- 2/3 (14kg?) from staff and patient transport (data?)

2. Utilities

- Electricity generation in Australia…
- Measurement of electricity usage? Small to medium businesses
- Surgical sterilisation (actual loads, tests, standby?)
- Total amount = 4.9kg CO_2e
- **Water**

Dermatologic Surgery: Results II

1. Instruments and Consumables

- Stainless steel surgical equipment:
  - 161 g = 0.86kg CO_2e for manufacture
  - = 1.07 kg CO_2e for transport…
- Plastics, gauze, etc.: 115g = 0.65 kg CO_2e
- Cotton gauze: 20 g = 110 g CO_2e (?)
- Latex glove: 10g = 50 g CO_2e

2. Waste

- Non-hazardous waste, biohazard, recyclables, sharps
- Non-hazardous= 'inert' (CH_4 capture leads to negative CO_2e)?…
- Hazardous waste: 0.23 kg = - 0.53 kg CO_2e

Dermatologic Surgery: Results III

1. Public Hospital vs. Private Clinic

- Cotton gown: 14. 55 kg CO_2e,
- Cotton 1 kg= 27 kg CO_2e
- So, the gown weighs half a kg; really?...
- Polypropylene gowns vs. cotton gowns
- Plastic drapes: 0.48 kg = 5. 75 kg CO_2e
- Washing: 1.8 kWh = 1.3 kg CO_2e
- 75% of sterilised instruments unused

2. In a Public Hospital

- Theatre HVAC Series of assumptions to reach 72 kg CO_2e (2.5 X Clinic)
- 10 X non-hazardous waste

Dermatologic Surgery: Recommendations

- Transportation…
- What % of skin lesions aren't so?
- Surgical issues: Full draping for minor surgery? …
- Surgery: avoid single use, discuss infection prevention requirements, recycle
- Reduce waste (avoid bottled water)
- Limitation? Process Based LCA. A bottom up vs. top down approach.
- (types of surgery, non-primary data etc.)

Dermatologic Surgery: Results II

1. Instruments and Consumables

- Stainless steel surgical equipment: 161 g = 0.86kg CO_2e
- Plastics, gauze, etc.: 115g = 0.65 kg CO_2e
- Cotton gauze: 20 g = 110 g CO_2e (?)
- Latex glove: 10g = 50 g CO_2e

2. Waste

- Non-hazardous waste, biohazard, recyclables, sharps
- Non-hazardous= 'inert' (CH_4 capture leads to negative CO_2e)?...
- Hazardous waste: 0.23 kg = - 0.53 kg CO_2e