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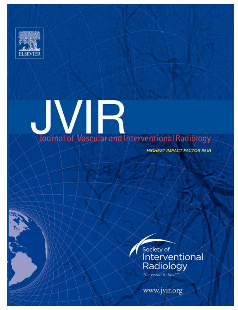

The environmental impact of interventional radiology: An evaluation of greenhouse gas emissions from an academic interventional radiology practice

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Title Page

The environmental impact of interventional radiology: An evaluation of greenhouse gas emissions from an academic interventional radiology practice

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Title

The Environmental Impact of Interventional Radiology: An evaluation of greenhouse gas emissions from an academic interventional radiology practice

Abstract

Purpose:

To calculate the volume of greenhouse gases (GHG) generated by a hospital-based interventional radiology department.

Materials and Methods:

Life cycle assessment (LCA) was used to calculate GHG emitted by an IR department at a tertiary care academic medical center during a single workweek. The volume of waste generated, the amount of disposable supplies and linens used, and the operating time of electrical equipment were recorded for each procedure performed between 7:00AM-7:00PM on five consecutive weekdays. LCA was then performed using purchasing data, plug loads for electrical hardware, data from temperature control units, and estimates of emissions related to travel in the area surrounding the medical center.

Results:

98 procedures were performed on 97 patients. The most commonly performed procedures were drainages (30 procedures), placement and removal of venous access (21 procedures), and CT guided biopsy (13 procedures). Approximately 23,500 kg CO_2e were emitted during the study. Sources of CO_2 emissions in descending order were those related to indoor climate control (11,600 kg CO_2e), production and transportation

of disposable surgical items (9640 kg CO_2e), electricity plug load for imaging, non-imaging, and lighting equipment (1060 kg CO_2e), staff transportation (524 kg CO_2e), waste disposal (426 kg CO_2e), production and laundering of linens (279 kg CO_2e), and gas anesthetics (19.3 kg CO_2e).

Conclusion:

The practice of interventional radiology generates substantial volumes of greenhouse gases, a majority of which come from energy used to power climate control followed by emissions related to the production and transportation of single use supplies. Efforts to reduce energy consumption and the use of disposable supplies may decrease GHG emissions and IR's contribution to climate change.

Introduction

The US healthcare system generates approximately 10% of the country's greenhouse gases, which impact global climate and are estimated to cause the loss of 405,000 disability life adjusted years from pollution-related diseases (1). As awareness of the healthcare industry's contribution to climate change spreads, physicians have been urged to examine behaviors which contribute to global warming and to innovate more sustainable practices (2–6). In response, there is a growing body of research focused on evaluating the environmental impact of different medical specialties (7–12). However, the volume of greenhouse gases emitted from procedures performed in interventional radiology (IR) remains unknown.

IR is a unique specialty in which invasive procedures are performed under the guidance of sophisticated imaging equipment. Like surgical specialties, IR requires the use of resource intense sterile supplies, specialized staffing, and facilities in which climate is controlled within set parameters. Like diagnostic radiology, IR requires the use of energy-intense imaging equipment. Given the unique combination of resources required to perform IR procedures, the volume and sources of GHGs produced by IR might differ from those previously reported for surgical specialties or diagnostic imaging. An evaluation of the factors which contribute to the production of GHGs is essential to design strategies to limit the environmental impact of IR.

The goal of this study was to use life cycle assessment (LCA) to estimate the volume and sources of greenhouse gases produced by an interventional radiology department at an academic medical center over the course of one week.

Methods

This study was conducted over one week (June 19-25, 2019) in the IR suite at (….) Hospital, a 300-bed tertiary care academic medical center in (….). Procedures performed between 7:00PM-7:00AM and procedures performed on weekends were excluded. The dates and hours during which the study was performed were chosen to maximize availability of personnel to collect data.

The evaluation and reduction of the environmental damage caused by the delivery of healthcare is an important priority for this medical center. This study met the institution's definition of research performed in the interest of quality improvement and did not require review by the institutional review board.

Study Location

The IR suite at (….) Hospital includes an intake area for outpatients; a control area containing 13 computer towers and 17 computer monitors; a 6-bed recovery room; a room with a CT scanner used for both procedures and diagnostic imaging; and three procedure rooms each containing a computer, a fluoroscopy unit, and an ultrasound unit.

On average, the IR suite is staffed by approximately 34 technologists, nurses, attending physicians, students, fellows, and resident physicians daily.

Data Collection

Data collected for the LCA is listed in Table 1. Prospective data was collected by a group of 5 undergraduate student auditors who alternated shifts. Data collected retrospectively was collected from patients' electronic medical records (EMR) and the medical center's finance and facilities management departments.

Waste Disposal and Soiled Linens

The practice at this medical center is to send general municipal waste to landfill and to autoclave then landfill solid and fluid biohazard waste. Sharps waste is autoclaved, shredded, then sent to landfill.

For rooms in which procedures were performed, bins containing soiled linens and municipal, solid biohazard, and sharps waste were weighed before and after every procedure. For the intake and recovery rooms, bins were weighed several times per day immediately before they were emptied by hospital housekeeping staff. Sharps waste was weighed using a portable Polysun American Weigh hanging scale (50 kg ± 0.01 kg) (American Weigh Scales; Cumming, GA). Other types of waste and linens were weighed using an Edlund ERS 60 scale (30 kg ± 0.005 kg) (Edlund Company; Burlington, VT).

Due to safety concerns, biohazard fluid waste was not weighed. Instead, data concerning volumes of fluid drained from patients were collected retrospectively from patients' medical records.

Patient gowns were removed outside of the IR suite and were not included in the audit.

Disposable Instruments and Supplies

For each procedure, a list of single-use supplies including surgical equipment such as wires, catheters, and stents, as well as items used outside of the patient such as sterile drapes, towels, and dressing materials, was generated from the EMR. The price the medical center paid the distributor of each item was collected from hospital financial records.

Gas Anesthetics

Volatile anesthetics are known to be long lasting and potent greenhouse gases. They undergo very little metabolism in vivo, and greater than 95% are exhaled into the atmosphere or back into the anesthesia circuit (13,14). While technology to trap exhaled gas anesthetics exists, it is not used at this medical center.

When a volatile anesthetic was used, the EMR was queried to determine the concentration at which the anesthetic gas was administered (%/L) and the average rate at which anesthetic and carrier gases were given over each 15-minute interval of the procedure. These values were multiplied, and the products were added together to calculate the total volume of gas anesthetic administered over the course of the procedure (9). This value was then multiplied by an anesthetic-specific CO2e conversion factor.

Energy Used by Imaging Units, Lighting, and other Electrical Equipment

The practice in this IR department is to turn off imaging equipment and lighting following completion of the last scheduled procedure of the workday. All other electrical equipment, including computers and monitors, are left on in idle mode. Because this medical center does not measure the electricity used in each individual room or department, electricity consumption was estimated based on the average power specifications for each device in the IR suite as listed by their manufacturers (Supplementary Table 1 for non-lighting equipment, Supplementary Table 2 for lighting) and the typical number of hours the hardware in each room was either in use, off, or in idle mode(Supplementary Table 3).

Energy Used by Heating, Ventilation, and Air Conditioning (HVAC) Systems

Energy used to maintain climate in the IR suite was estimated using the bin model described by Thiel et al based on the floor area, room temperature, outdoor air ratio, humidity set points, and number of air changes per hour in each room (Supplementary Table 4) (9,15). The bin model estimates the electricity and natural gas used to maintain the IR suite over the course of an entire calendar year and takes into account seasonal variations from conditioning outdoor air, variations in room occupancy, and differences in settings and wattage during working and non-working hours. This cumulative annual value was then used to calculate the total HVAC energy used during the audit period.

GHGs generated by the use of electricity varies in different parts of the country due to regional differences in the mix of natural gas, coal, hydroelectric and other sources of energy used to create electricity. Though the study hospital sources electricity from both the local energy provider and an on-site natural gas powered co-generation facility, the relative share of energy supplied by each source varies and cannot be tracked precisely in each area of the hospital. Therefore, it was assumed for the purposes of this study that the electricity used during the audit was generated from the average electricity mix for the entire United States. This simplifying assumption enables greater comparisons with other hospital locations across the US, few of which have similar electric power plants on site.

Commutes of Staff

In order to estimate the carbon footprint from staff members' commutes, the following assumptions were made: members of staff have the same residential distribution as that of adult (….) area residents reported from data from the 2010 census (16); they live in the population center of each borough or suburb from which they were assumed to live; and they use the same mix of transportation modes as those of other workers who commute to (….) (17).

Because many of the patients treated during the study were inpatients whose travel could not be allocated to different procedures and because some outpatients travelled from locations that did not correspond to the residential addresses recorded in their medical record, emissions generated by patients' commutes were not evaluated. The commutes of housekeeping, patient escort and other staff members who work primarily in other areas of the hospital and spend only short periods of time in the IR suite were not included.

Life Cycle Inventory and Impact Assessment

Data collected during the study was analyzed using life cycle assessment. LCA is a tool used in sustainability research to estimate cumulative GHG and other emissions from a process or product over the course of its lifetime from extraction of raw materials through manufacturing, transportation, use, and disposal. An LCA is conducted in 4 stages: 1) the goals and scope of the study are defined; 2) a lifecycle inventory is conducted to enumerate and quantify all sources of emissions from each product or process under study; 3) an impact assessment is performed to determine the emissions' effects on one or more specific environmental categories such as GHG emissions, ozone depletion, or smog formation; and 4) results of the LCA are interpreted (18, 19).

For the purposes of this study, each IR procedure was defined as an independent functional unit. The study boundaries for each unit are described in Figure 1. The resources which were used and the waste which was generated for each procedure in the four areas of the IR suite were measured as described above, and LCA was performed for each of the inputs listed in Table 2.

For inputs which were discrete processes or products which could be quantified and for which data regarding emissions are available, a process LCA was performed. For each process LCA, a life cycle inventory was created by matching the material and energy used for each procedure with unit processes in the Ecoinvent 3.3 emissions database (Ecoinvent; Zurich, Switzerland) using the SimaPro version 8.5.2.0 interface software (PRe' Sustainability; Amersfoort, The Netherlands) (20, 21).

The process LCA for linens included data on emissions per unit mass from the production, industrial cleaning, and disposal of bedsheets and blankets collected from the Ecoinvent database. Each piece of linen was assumed to have an average lifespan of 20 uses based on estimates from hospital housekeeping and supply chain staff. The process LCA for waste disposal was based on emissions per unit mass from shredding sharps waste, autoclaving biohazard and sharps waste, and disposing of municipal, biohazard, and sharps waste as described in the Ecoinvent database.

For surgical supplies, there is limited lifecycle data regarding the environmental impact of specific instruments. Therefore, a hybrid analysis was performed using an environmentally extended input-output LCA (EEIO LCA). In EEIO LCA, the price of a product is used to estimate its environmental impact based on the assumption that price is set partly based on the amount of energy and resources required to manufacture and transport the product. The EEIO LCA model creates a conversion factor (impact per dollar) based on the economic sector from which the product is manufactured (22, 23). The most recent EEIO LCA model uses emissions data from 2013, so to calculate emissions from surgical supplies used during the audit, the price the medical center paid for equipment opened during each procedure was deflated from 2019 to 2013 US dollar equivalents using the US Bureau of Labor Statistics Producer Price Index (24). The US environmentally extended input-output database (22) and the interface software OpenLCA (GreenDelta; Berlin, Germany) (25) were then used to calculate the conversion factor for the manufacturing of surgical supply (0.20639 kg CO2e per 2013 USD). This factor was multiplied by the 2013 USD costs to yield the estimated emissions from supplies in our study.

The different types of greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, etc.) calculated from the process and EEIO LCAs were converted to equivalent units of carbon dioxide (CO_2e) using the US Environmental Protection Agency's Tool for the Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 version 1.04 (26) to determine their impact on climate change.

Statistical Analysis

Statistical analysis was performed using R version 3.5.3 (R Core Team, 2020). Data was analyzed to determine the total volume of GHGs emitted during the audit and the contribution of the different sources of emissions listed in Table 2.

Results

Patient demographics and procedure characteristics

During the five-day audit, 98 procedures were performed on 97 patients. The mean age of patients was 57.7 years (range 12-94 years); 42 patients (43%) were female(Supplementary Table 5). The types and numbers of procedures performed are described in Table 3.

Waste Generation, Linen Use, and Cost of Supplies

Approximately 366 kg municipal solid waste, 260 kg solid and fluid biohazard waste, 20 kg sharps waste, and 168 kg of linens were generated during the audit. 496 kg (77%) of waste originated from procedure rooms; the remainder originated from the intake and recovery areas. On average, each procedure used approximately $490 (SD=$1410) of disposable equipment, sent 1.71 kg (SD=1.22 kg) of linens for laundering, and generated 3.73 kg (SD=2.93 kg) of municipal waste, 2.65 kg (SD=3.40 kg) of biohazard solid and fluid waste, and 0.20 kg (SD=0.26 kg) of sharps waste (Figure 2 and Table 4).

Greenhouse Gas Emissions

The IR department generated approximately 23,500 kg CO_2e during the audit (mean 243 kg CO_2e/procedure, median 159 kg CO_2e /procedure). Electricity and gas used to power the climate control system represented the largest source of emissions (11,600 kg CO_2e or 49%). More than half (57%) of HVAC energy use occurred outside of scheduled working hours when few procedures were performed and the unit was largely unoccupied.

The second largest source of GHG emissions was the production and delivery of single use surgical supplies (9640 kg CO_2e or 41% of total). The absolute and relative contributions of other sources of emissions are described in Table 4 and Figure 3.

The 7 patients who received gas anesthesia during the study period were given sevoflurane. The calculated greenhouse gas emissions from the use of sevoflurane was 19.3 kg CO_2e (<0.1% of total), though this is felt to be an overestimate since an unquantifiable portion of exhaled anesthetic was recirculated to the anesthesia equipment (Figure 4).

Average distance of staff commute was calculated to be 11.2 km. Staff commuting accounted for 524 kg CO_2e (2.2% of total emissions), an average of 15.4 kg CO_2e per staff member.

Discussion

Over the course of one week, a hospital-based interventional radiology department generated approximately 23,500 kg CO_2e. This is equivalent to the emissions generated by burning approximately 2,640 gallons (9,990 L) of gasoline or by driving an average passenger vehicle 58,300 miles (93,800 km). It would take 389 young trees 10 years to sequester this amount of carbon (27). The largest sources of GHG emissions were energy used to maintain climate in the IR suite followed by emissions related to the production and delivery of single-use equipment. Of note, over half of the emissions related to the use of the climate control system – slightly greater than a quarter of the emissions from the entire audit – were generated during off hours while the suite was rarely in use.

Given the paucity of published data and the fact that settings and LCA methodologies differ between studies, it is difficult to compare average per procedure emissions observed in this study with those reported in the surgical literature. For example, a study of operating theaters at three different medical centers estimated average per surgery emissions of 146-232 kg CO_2e, though the authors felt that their methodology underestimated emissions related to the production and delivery of surgical supplies (10). In a systematic review of sustainability studies performed in the operative setting, Rizan et al found that the carbon footprint of a single operation was reported to range from 6 kg CO_2e for cataract surgery performed at a site in India to 814 kg CO_2e for a robotic hysterectomy performed in the United States (28). Emissions from studies included in this review varied depending on the boundaries and assumptions included in each LCA. The current study's finding that IR procedures generated an average of 243 kg CO_2e and a median of 159 kg CO2e places these procedures at the middle to lower end of what has been reported in LCAs of operative procedures, though direct comparison of carbon emissions between studies must be made with caution.

Despite differences in methodology, some helpful comparisons regarding the sources of emissions from practices in other specialties can be made. This study's finding that energy use is the dominant source of GHG emissions is consistent with previously reported studies performed both in diagnostic imaging and in the surgical setting. For example, Heye et al found that over the course of a year, 3 CT scanners and 4 MRI scanners used enough electricity to power a town of 852 people (29). Marwick, et al. found that electricity use accounted for 98% of the environmental damage caused by cardiac MRI (30). Like the current study, LCAs performed in the operative setting have found that climate control systems and the production and delivery of single use supplies are dominant sources of emissions from surgical procedures (9, 11, 28, 31). Given that IR uses energy-consuming imaging equipment and that the climate in the IR suite needs to be maintained within set parameters similar to an OR, it is not surprising that energy use was the largest source of GHG emissions in this study.

In contrast to LCAs which have found that the use of anesthetic gases is a major source of GHG emissions from surgery (9, 10), this study found that the use of anesthetic gases generated a relatively small percentage of emissions from the IR suite This is due to the fact that most patients in this study did not undergo general anesthesia. The few patients who did receive anesthetic gases were treated with sevoflurane, a powerful but less potent GHG than some agents described in previous reports, such as desflurane (10,32).

The findings of this study suggest that a strategy to "reduce, reuse, and recycle" that has been implemented in ORs may help to decrease emissions from IR as well. For example, efforts to reduce emissions from electricity use may include shutting off imaging equipment, computers, and lighting, decreasing the number of air exchanges, and allowing climate control systems to drift within a wider range of temperatures during times outside scheduled working hours (31). Strategies to reduce GHG emissions from disposable equipment may include re-designing procedure packs to minimize items which are likely to be thrown away without being used (33). Strategies to reuse items may include decreasing the use of supplies designed for single use in favor of items which can be safely reprocessed, including surgical instruments and gowns. Initiatives to recycle may include efforts to properly sort non-infectious cardboard, paper, and plastic from the IR suite into the recycling stream and to strategically donate older or unused equipment and supplies to hospitals in developing countries to prolong their use (34, 35). When implemented in the OR, such strategies have been reported to decrease the environmental impact of surgery and may lead to cost savings for hospital systems (36, 37).

This study has several limitations. First, the study includes data from only one week of observations and did not include procedures performed at night or on weekends. Though a longer audit may be preferable, the volume of data collected and analyzed in this study compares favorably with previously published LCAs performed in the healthcare setting. Furthermore, the volume and types of procedures performed during the week of the audit was fairly typical for this IR department, and the audit is felt to reflect the types of data that would be collected during a longer period of observation. Second, the volumes of GHG emissions reported in this study reflect the imaging and surgical equipment, case mix, local practices, staffing levels, and commutes specific to this hospital. While GHG emissions from other IR practices will vary, the relative contributions of the dominant sources of GHG emissions are likely to be similar.

Like previously published LCAs performed in the operative setting, this study does not calculate GHG emissions related to the post-procedural management of hospitalized patients. A more comprehensive study would include an assessment of emissions related to all aspects of peri-procedural care, including for hospital inpatients.

Finally, this study used an EEIO LCA to estimate the impact of single use supplies. EEIO LCA relies on the cost of supplies to estimate the environmental impact of their production and transportation and is limited by the fact that there are many additional factors which help to determine the price a hospital pays for equipment, only some of which are accounted for by application of an industry specific emissions conversion factor. While EEIO methodology is limited, there are few alternatives given the lack of publicly available data regarding emissions from the production and delivery of surgical supplies. Though it is not ideal, the hybrid approach used for this study has been used in multiple LCAs performed in the healthcare setting and is felt to reflect best available practices (9, 11, 38).

Conclusion

In summary, this LCA found that a hospital-based IR department generated substantial amounts of GHGs, the primary sources of which were electricity and gas used to power the climate control system and emissions related to the production and delivery of single use supplies. Strategies designed to decrease these sources of emissions may help to mitigate interventional radiology’s harmful impact on the environment and public health.

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Legends for Figures (included in .TIFF document)

Figure 1: Flow diagram and boundary conditions of the audit. Patient movement through the unit is left-to-right, while resource movement is top-to-bottom. Arrows pointing to or from the solid boundary show that the item category referenced is found throughout the suite.

Figure 2: Mean per procedure cost of single use equipment and weight of linens, municipal, biohazard, and sharps waste. Error bars represent standard deviation.

*Figure 3: Volumes of greenhouse gases (GHGs) generated during the audit. Energy used to power the climate control system in the IR suite was the largest source of GHG emissions. More than half of the emissions from the climate control system occurred at night and during the weekend when the suite was largely unoccupied. *Gas anesthetic was used for 7 procedures. **Linens include one laundry process and the impacts of production and disposal allocated over the estimated lifespan of each piece of linen. ***Waste Disposal includes emissions related to the disposal of municipal, biohazard, and sharps waste. †Shaded portion of climate control represents energy used during off hours.*

Figure 4. Gas flow rates and percentage sevoflurane by volume of gas administered to the seven patients (P1-P7) who received gas anesthesia during the study, reported in time steps of 15 minutes. The value next to each label at the bottom of the figure is the calculated volume of sevoflurane used for each patient. Note: Because some exhaled anesthetic is recirculated back

to the anesthesia equipment, the calculated volumes likely overestimate the volume of sevoflurane leaked to the environment. Gas flow rate= flow rate of anesthetic + carrier gases.

Table 1 (Supp). Plug loads and model information for computers, imaging equipment, and anesthesia machines in the IR suite.

Room	Item	Count	Equipment Type	Plug Load while Active [W] (for Imaging Equipment)	Plug Load during On-hours [W]	Plug Load during Off-hours [W]
Intake	Dell OptiPlex	5	Computer	---	25	1.5
	Dell Wyse 5010	1	Computer	---	7.7	0.74
	Dell Wyse 5020	1	Computer	---	6.3	0.6
	Dell Monitor P2210	1	Monitor	---	22	0.3
	Dell Monitor LCD P2412H	4	Monitor	---	21	0.1
	Dell Monitor LCD P2417H	1	Monitor	---	19	0.3
	Signage display	2	Display	---	122	0.5
Recovery	Dell OptiPlex	2	Computer	---	25	1.5
	Dell Wyse 5070 Thin Client	3	Computer	---	65	4.6
	Dell Wyse 5020	1	Computer	---	6.3	0.6
	HP rp5800	1	Computer	---	240	---
	Dell Monitor LCD P2417H	1	Monitor	---	19	0.3
	Dell Monitor LED P2213	1	Monitor	---	25	0.3
	Dell Monitor LCD E2211HC	1	Monitor	---	20	1.0
	Dell Monitor LCD P2212H	3	Monitor	---	21	0.1
	Elo touchscreen monitor	1	Monitor	---	20	2.0
	Follet Ref5P	1	Refrigerator	---	75	75
Control Room	Dell OptiPlex	7	Computer	---	25	1.5
	Dell Precision Workstation	2	Computer	---	164	4.6

	T5600					
	Dell Wyse 5020	2	Computer	---	6.3	0.6
	Fujitsu CELSIUS	2	Computer	---	250	---
	Barco Nio Color MDNC-2221	4	Monitor	---	50	1
	Dell Monitor U2410	6	Monitor	---	75	1
	Dell Monitor P2417H	3	Monitor	---	19	0.3
	Siemens Monitor DSB 1908-DC	2	Monitor	---	8	1.5
	Siemens Monitor DSC 1703-D	1	Monitor	---	9	1.5
	Planar PS5552	1	Display	---	122	0.5
	Samsung MD65C	1	Display	---	230	1
Procedure Room 1	Siemens ACUSON S2000 HELX Evolution Ultrasound	1	Imaging	570	30	30
	Siemens Axiom Artis Angiography System	1	Imaging	8100	5000	1400
	MEDRAD Mark V Provis Angiographic Injection System	1	Ancillary Imaging	880	---	---
	Dell OptiPlex	2	Computer	---	25	1.5
	Dell Monitor HD P2414Hb	1	Monitor	---	19	0.25
	Dell Monitor LED P2213	1	Monitor	---	25	0.3
	Siemens Monitor DSB 1803-DC	2	Monitor	---	8	1.5
Procedure Room 2	Siemens ACUSON S3000 HELX	1	Imaging	570	30	30

	Evolution Ultrasound					
	Siemens Axiom Artis Angiography System	1	Imaging	8100	5000	1400
	MEDRAD Mark V Provis Angiographic Injection System	1	Ancillary Imaging	880	---	---
	Dräger Apollo Anesthesia Workstation	1	Anesthesia	200	---	---
	Dell OptiPlex	1	Computer	---	25	1.5
	Dell Wyse 5020	1	Computer	---	6.3	0.6
	Dell Wyse 5070	1	Computer	---	4.6	1.5
	Dell Monitor LCD E2211HC	1	Monitor	---	20	1.0
	Dell Monitor E2211H	1	Monitor	---	55	2.0
	Siemens Monitor DSB 1908-DC	4	Monitor	---	8	1.5
	Planar PT1975R	1	Monitor	---	15	4
Procedure Room 3	Siemens ACUSON S2000 HELX Evolution Ultrasound	1	Imaging	570	30	30
	Siemens Axiom Artis Angiography System	1	Imaging	8100	5000	1400
	MEDRAD Mark V Provis Angiographic Injection System	1	Ancillary Imaging	880	---	---
	Dräger Apollo Anesthesia Workstation	1	Anesthesia	200	---	---
	Dell OptiPlex	1	Computer	---	25	1.5

	Dell Wyse 5020	1	Computer	---	6.3	0.6
	Dell Monitor LCD E2211HC	1	Monitor	---	20	1.0
	Siemens Monitor DSB 1803-DC	5	Monitor	---	8	1.5
	Planar PT1975R	1	Monitor	---	15	4
CT Room	Siemens SOMATOM Definition AS	1	Imaging	125,000	4000	2500
	Bracco EmpowerCTA+ Contrast Injection System	1	Ancillary Imaging	250	---	---
	Dell Monitor LCD P2212H	1	Monitor	---	21	0.1
	Eizo Monitor DSC 1908-DC	1	Monitor	---	8	1.5

Table 2 (Supp). Plug loads for lighting used in the IR suite.

Room	Item	Count	Plug Load during On-hours [W]	Plug Load during Off-hours [W]
Intake	Fluorescent lamp (2), Power ballast (1)	4	48	9.6
Recovery	Fluorescent lamp (4), Low-power ballast (1)	1	84	0
Control Room	Fluorescent lamp (2), Power ballast (1)	1	48	48
Procedure Room 1	Fluorescent lamp (2), Power ballast (1)	2	29	5.8
	Fluorescent lamp (6), Low-power ballast (3)	8	126	25.2
Procedure Room 2	Fluorescent lamp (2), Power ballast (1)	2	29	5.8
	Fluorescent lamp (6), Low-power ballast (3)	8	126	25.2
Procedure Room 3	Fluorescent lamp (2), Power ballast (1)	2	29	5.8
	Fluorescent lamp (6), Low-power ballast (3)	8	126	25.2
CT Room	Fluorescent lamp (2), Power ballast (1)	2	29	5.8
	Fluorescent lamp (6), Low-power ballast (3)	8	126	25.2

Table 3 (Supp). Scheduled working and non-working hours for rooms in the IR suite.

Room	Working hours [hr]	Non-working hours [hr]
Intake	8.5	15.5
Recovery	12	12
Control Room	12	12
Procedure Room 1	8.5	15.5
Procedure Room 2	12	12
Procedure Room 3	12	12
CT Room	8	16

Table 4 (Supp). Climate control information for rooms in the IR suite.

Room	Floor Area [m^2]	OA Ratio	Air Changes per Hour	Room Temperature [°C]	Relative Humidity [%]
Intake	920	0.33	6	22.5	60
Recovery	48.8	0.5	4	22.5	60
Control Room	38.3	0.2	2	22.5	60
Procedure Room 1	39.9	0.2	15	22.5	60
Procedure Room 2	48.7	0.2	15	22.5	60
Procedure Room 3	46	0.2	15	22.5	60
CT Room	37	0.33	6	22.5	60

Table 5 (Supp). Patient demographics during audit.

Variable	N (%)
Total Number of Patients	97 (100)
Age (Mean (SD))	57.74 (16.33)
Age distribution (years)	
<=20	2 (2.1)
21-40	14 (14.4)
41-60	32 (33.0)
61-80	44 (45.4)
>80	5 (5.2)
Gender	
F	42 (43.3)
M	55 (56.7)

Table 1—Data collection

Prospective	Retrospective
• Age and sex of patient • Procedure type • Type(s) of imaging equipment used • Weight of waste sorted into general, biohazard, and sharps containers* • Weight of linens used for each patient*	• Types and cost of single use equipment used for procedure • Volume of biohazard fluid generated for paracentesis and other drainage procedures** • Volume of sevoflurane administered (when applicable) • Plug loads for imaging and other electronic hardware • Number of hours imaging equipment were in use, idle, and off

* Municipal waste, solid biohazard waste and linens were weighed using an Edlund ERS 60 scale (30 kg ± 0.005 kg). Sharps waste was weighed using a portable Polysun American Weigh scale (50 kg ± 0.01 kg).

**Due to difficulties safely weighing biohazard fluid, data concerning volumes of fluid drained from patients were collected retrospectively from patients' medical records.

Table 1: Data collected to calculate greenhouse gas emissions generated during the study period. Prospective data was collected by a team of five auditors. Retrospective data was collected from patient medical records and hospital financial, facilities, and engineering logs.

Table 2—Life Cycle Assessment (LCA) Performed for Each Emissions Category

Process LCAs	EEIO LCAs
• Electricity used to power imaging and other electronic equipment, lighting • Laundering and reprocessing of linens • Disposal of general, sharps, and biohazard waste • Climate control system • Gas anesthesia (sevoflurane) • Staff commutes	• Production and delivery of single use equipment
EIO= Environmentally extended input-output	

Table 2: Table lists the process and EEIO LCAs used to calculate greenhouse gases generated during each procedure observed during the study period. EEIO= Environmentally extended input-output life cycle assessment

Table 3—Procedures Performed During Audit

N (%)	Variable				
Total procedures	98 (100)				
By Modalities	**N (%)**	***By Patient Disposition***	**N (%)**	***By Procedure Category***	**N (%)**
US	30 (30.6)	*Inpatient*	34 (34.7)	*Biliary*	5 (5.1)
Fluoroscopy	13 (13.3)	*Outpatient*	64 (65.3)	*Biopsy, CT*	13 (13.3)
US and fluoroscopy	35 (35.7)			*Biopsy, Transvenous*	1 (1.0)
CT	17 (17.3)			*Biopsy, US*	8 (8.2)
No imaging used	3 (3.1)			*Drainage*	30 (30.6)
				Embolization, Arterial	4 (4.1)
				Gastrointestinal	1 (1.0)
				Genitourinary	5 (5.1)
				Lumbar Puncture	4 (4.1)
				Portal Venous	3 (3.1)
				Diagnostic Arteriography	2 (2.0)
				Systemic Venography and Intervention	1 (1.10)
				Venous Access	21 (21.4)

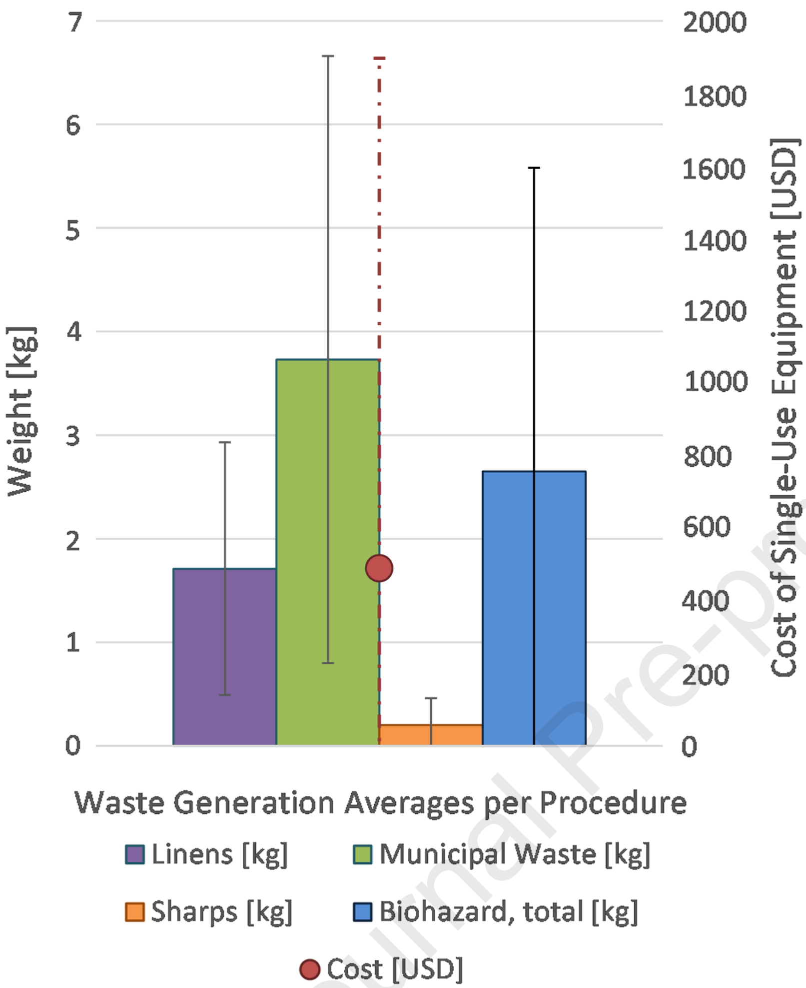
Table 3: Table describes the number of procedures performed during the audit broken down by procedure category, patient disposition, and the imaging modality used to perform the procedure.

Table 4—Results of Audit and Assessment of Greenhouse Gas Emissions

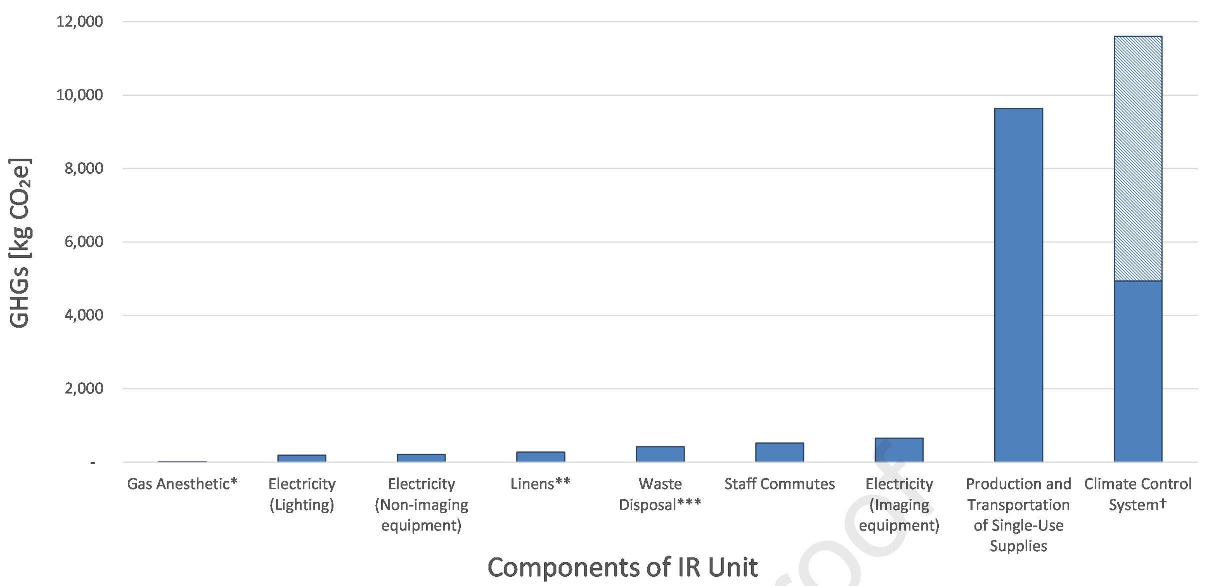
Variable	Total during Audit Period	Mean (SD) per Procedure	Median (IQR)	Relative Contribution to Total GHGs
Procedures [N]	98	---	---	---
Cost of Single Use Equipment [USD]	48,000	490 (1410)	91.6 (57.8, 223)	---
Municipal Waste [kg]	366	3.73 (2.93)	2.96 (1.85, 4.57)	---
Linens [kg]	168	1.71 (1.22)	1.22 (0.89, 2.25)	---
Sharps Waste [kg]	19.6	0.20 (0.26)	0.13 (0.09, 0.23)	---
Biohazard, Total [kg]	260	2.65 (3.40)	1.25 (1.25, 1.30)	---
Biohazard, Solid [kg]	11.8	0.12 (0.37)	0.059 (0.059, 0.059)	---
Biohazard, Fluid [kg]	248	2.53 (3.27)	1.19 (1.19, 1.20)	---
GHG Total [kgCO2e]	23,500	243 (297)	159 (144, 192)	100%
GHG HVAC [kgCO2e]	11,600	118 (17.4)	115 (111, 124)	49.2%
GHG Single Use Disposable Equipment [kgCO2e]	9,640	98.4 (282)	18.4 (11.6, 44.8)	41.0%
GHG Municipal Waste [kgCO2e]	186	1.90 (1.49)	1.50 (0.94, 2.33)	0.79%
GHG Linens [kgCO2e]	279	2.84 (2.05)	2.05 (1.50, 3.77)	1.19%
GHG Sharps Waste [kgCO2e]	17.7	0.18 (0.24)	0.12 (0.08, 0.21)	0.08%
GHG Biohazard Total [kgCO2e]	222	2.26 (2.90)	1.08 (1.08, 1.12)	0.94%
GHG Biohazard, Solid [kgCO2e]	24.4	0.25 (1.29)	0.05 (0.05, 0.05)	0.10%
GHG Biohazard,	197	2.01 (2.66)	1.03 (1.03, 1.03)	0.84%

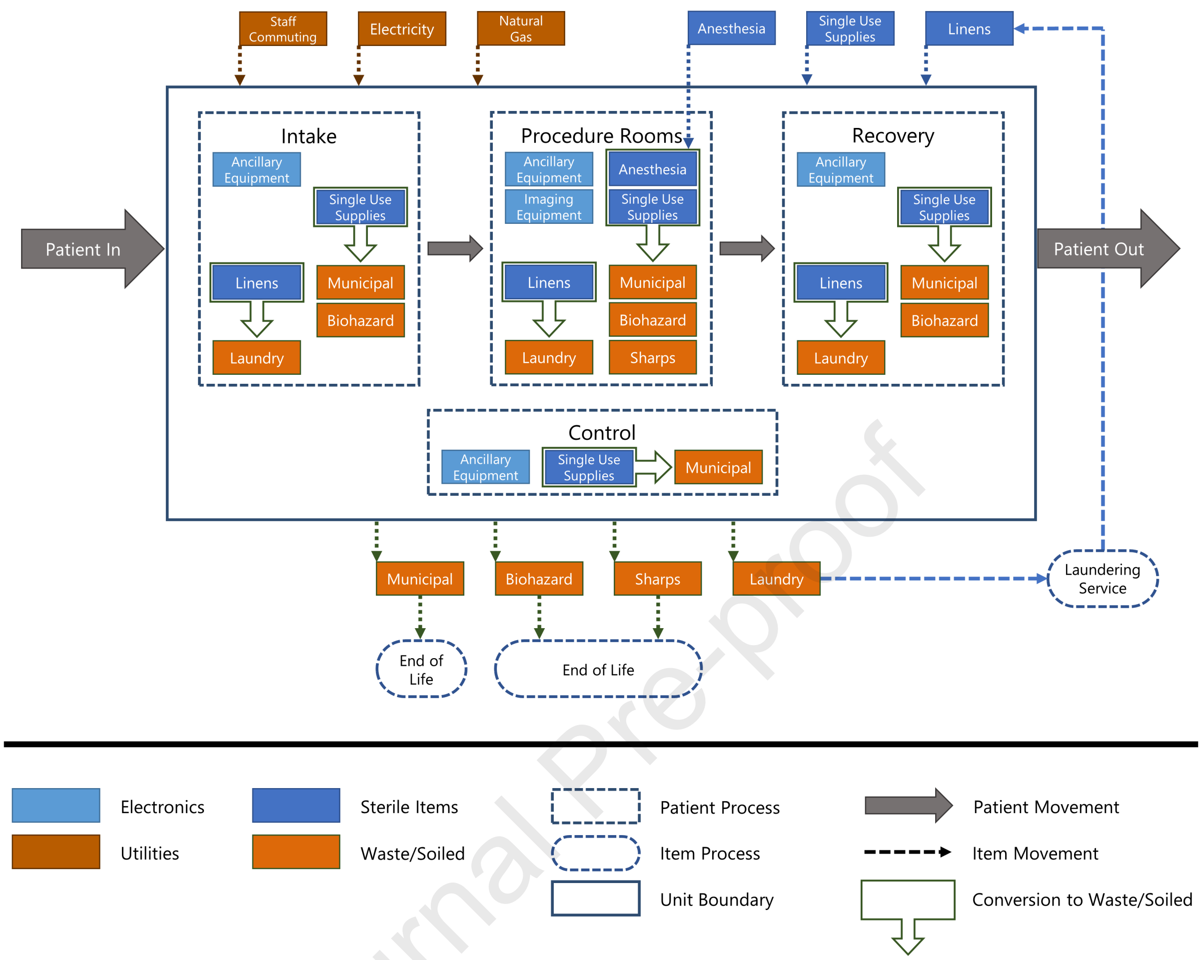
Fluid [kgCO2e]				
GHG Plug Loads Total [kgCO2e]	867	8.85 (4.24)	7.37 (6.07, 9.36)	3.69%
GHG Plug Loads, Non-Imaging [kgCO2e]	213	2.17 (0.84)	1.78 (1.59, 2.66)	0.90%
GHG Plug Loads, Imaging [kgCO2e]	655	6.68 (3.88)	4.93 (3.86, 8.79)	2.78%
GHG Lighting [kgCO2e]	194	1.98 (0.73)	1.82 (1.60, 2.09)	0.82%
GHG Staff Transportation [kgCO2e]	524	5.34 (0.38)	5.40 (5.40, 5.40)	2.23%
GHG Sevoflurane [kgCO2e]	19.3	0.20 (0.95)	0.00 (0.00, 0.00)	0.08%

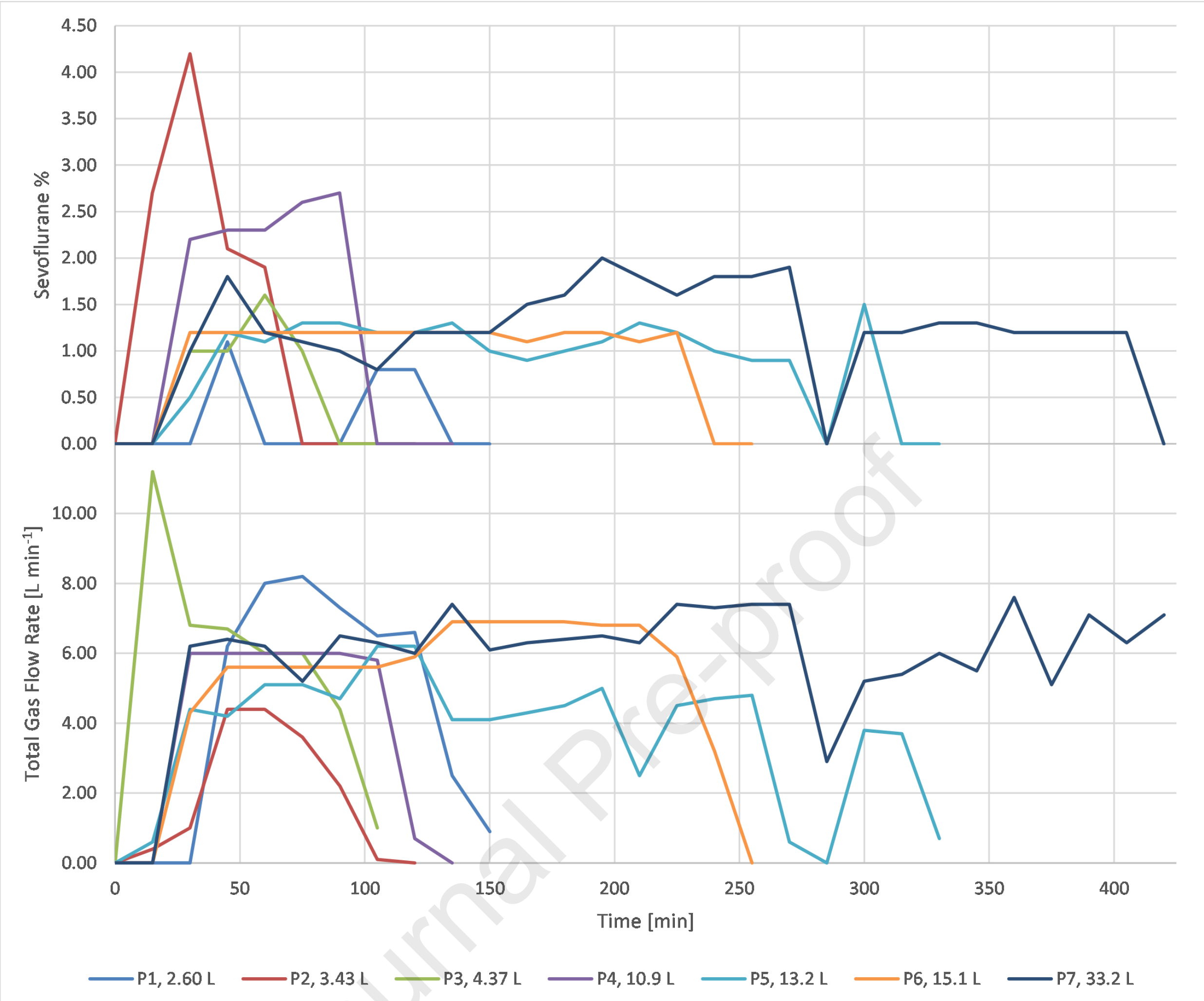
Table 4: The total, mean, median, and standard deviation for cost of single use equipment, weight of different types of waste, and calculated volumes of greenhouse gases (GHGs) produced during the audit. Up to three significant figures were used to report values.



7
6
5
4
3
2
1
0
Weight [kg]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Cost of Single-Use Equipment [USD]
Waste Generation Averages per Procedure
Linens [kg]
Municipal Waste [kg]
Sharps [kg]
Biohazard, total [kg]
Cost [USD]


12,000
10,000
8,000
6,000
4,000
2,000
-
GHGs [kg CO_2e]
Gas Anesthetic*
Electricity (Lighting)
Electricity (Non-imaging equipment)
Linens**
Waste Disposal***
Staff Commutes
Electricity (Imaging equipment)
Production and Transportation of Single-Use Supplies
Climate Control System†
Components of IR Unit


Staff Commuting
Electricity
Natural Gas
Anesthesia
Single Use Supplies
Linens
Patient In
Intake
Ancillary Equipment
Single Use Supplies
Linens
Municipal
Biohazard
Laundry
Procedure Rooms
Ancillary Equipment
Anesthesia
Imaging Equipment
Single Use Supplies
Linens
Municipal
Biohazard
Laundry
Sharps
Recovery
Ancillary Equipment
Single Use Supplies
Linens
Municipal
Biohazard
Laundry
Patient Out
Control
Ancillary Equipment
Single Use Supplies
Municipal
Municipal
Biohazard
Sharps
Laundry
Laundering Service
End of Life
End of Life
Electronics
Sterile Items
Patient Process
Patient Movement
Utilities
Waste/Soiled
Item Process
Item Movement
Unit Boundary
Conversion to Waste/Soiled


Sevoflurane %
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Total Gas Flow Rate [L min-1]
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
350
400
Time [min]
P1, 2.60 L
P2, 3.43 L
P3, 4.37 L
P4, 10.9 L
P5, 13.2 L
P6, 15.1 L
P7, 33.2 L