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The Energy and Environmental Burden of Australian Ambulance Services

Thesis submitted by

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Master of Public Health and Tropical Medicine

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For the Degree of Doctor of Philosophy

In the School of Public Health,
Tropical Medicine and Rehabilitation Sciences
James Cook University

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The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the National Statement on Ethics Conduct in Research Involving Humans (1999), the Joint NHMRC/AVCC Statement and Guidelines on Research Practice (1997), the James Cook University Policy on Experimentation Ethics: Standard Practices and Guidelines (2001), and the James Cook University Statement and Guidelines on Research Practice (2001).

The research in this thesis received approval from the James Cook University Human Research Ethics Committee (approval numbers: H3592; H4277; H3982). The approval documents are included in Appendix 1.

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Citations for, and the Contributions of Other Authors to, Published or Submitted Works Resulting from or Contributing to this Thesis

Brown, L.H., Canyon. D.V., Buettner, P.G. (In Press). The energy burden and environmental impact of health services: A review. *American Journal of Public Health*. Based on Chapter 3.

> Author contributions: LHB devised and executed the search strategy, reviewed the identified papers and extracted the relevant data, and drafted the manuscript. DVC and PGB reviewed and provided guidance on the search strategy, and provided critical review of the final manuscript.

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> Author contributions: LHB developed the study design and data collection process, established the linkages with the participating organisations, conducted the data analysis and drafted the manuscript. DVC, PGB, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.

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Author contributions: LHB developed the study design, collected the data, conducted the data analysis and drafted the manuscript. DVC, PGB, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.

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Author contributions: LHB developed the study design, collected the data, conducted the primary data analysis and drafted the manuscript. TC provided guidance on and assisted with the data analysis and the interpretation of the results. TC, PGB, DVC, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.

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Author contributions: LHB and IEB developed and executed this post hoc analysis. LHB drafted the manuscript; IEB provided critical review of the manuscript. A significant revision to the manuscript occurred as a result of the peer-review process. LHB and IEB contributed equally to that revision.

Documentation of acceptance for manuscripts arising from this thesis that are in press is included in Appendix 2. The published versions of manuscripts arising from or contributing to this thesis that were published as of the date of submission are included in Appendix 3. Contributing author verification of their contributions is included in Appendix 4.

Contributions by Others to the Thesis as a Whole

Dr. Petra Buettner and Dr. Deon Canyon (my primary supervisors) contributed significantly to the process of refining and focusing the original concept for this thesis, and to the drafting of all the Chapters. Dr. John “Mac” Crawford and Dr. Jenni Judd also provided critical review and comment on the thesis as a whole. Dr. Taha Chaiechi and Dr. Petra Buettner were both instrumental in my efforts to learn about, and conduct, the panel data analyses in Chapter 6. Although Ian Blanchard did not formally contribute to this thesis, he did make substantial contributions to one of the “…Works Resulting from or Contributing to this Thesis” (as described above) and to the “Additional Relevant Works … not Forming Part of this Thesis” (described below). I certainly made use of those shared experiences in completing this work. Also, all of the Chapters in this thesis that have undergone peer review have benefited greatly from the feedback of the anonymous reviewers.

Ms. Kim Pritchard provided professional proof reading and editing for this thesis, limited to Standards D and E of the Australian Standards for Editing Practice.

Parts of the Thesis Submitted to Qualify for the Award of another Degree

None.

Additional Relevant Works Published by the Author but not Forming Part of the Thesis

Blanchard, I., Brown, L.H. (2009). Carbon footprinting of EMS systems: A proof of concept study. *Prehospital Emergency Care*, 13, 546-549.

Blanchard, I.E., Brown, L.H., on behalf of the North American EMS Emissions Study Group. Carbon footprinting of North American EMS systems. (2011). *Prehospital Emergency Care*, 15, 23-29.

The published versions of these related manuscripts are included in Appendix 5.

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Thank you, Ian, for inspiring me to pursue such an odd-ball but important topic, and for keeping me motivated along the way.

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Thank you, Tony, for suffering my absence and all of the uncertainty. You deserve better.

Thank you, mom, for everything.

Abstract

Background:

Ambulance services are a vehicle-intense sector of healthcare and, as such, are particularly vulnerable to the threats posed by energy scarcity, rising energy costs, and tightening constraints on greenhouse gas emissions. The objective of this thesis is to establish the energy- and environmental-burden of Australian ambulance services.

Aims:

This thesis encompasses four specific aims: (1) Review the literature on the energy consumption and environmental impact of health services; (2) Identify the primary sources, and measure the amount, of greenhouse gas emissions arising from the direct and purchased energy consumption of Australian ambulance systems; (3) Estimate the complete life cycle greenhouse gas emissions of Australian ambulance systems, including emissions arising upstream in the supply chain; and (4) Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian ambulance systems.

Methods:

The PubMed, CINAHL and *ScienceDirect* databases were searched—along with the tables of contents of 12 energy and economics journals—to identify publications reporting energy consumption, greenhouse gas emissions, and/or environmental impacts of health-related activities. Data were extracted and tabulated to enable cross-comparisons among different activities and services; where possible, per-patient or per-event emissions were calculated.

Next, a two-phase study, including a test-retest pilot trial to establish consistency in the data collection process, used operational and financial data from a convenience sample of Australian ambulance operations to inventory their energy consumption and greenhouse gas emissions for one year. Inventoried energy sources included petrol, diesel, aviation fuels, electricity, natural gas, compressed natural gas, liquefied petroleum, fuel oil, and employee travel. Ambulance systems serving 58% of Australia's population and performing 59% of Australian ambulance responses provided data for the study.

To estimate complete life cycle emissions from Australian ambulance agencies, data from the inventory of direct and purchased energy consumption were combined with input-output based emissions estimates generated using aggregate ambulance system financial data and published emissions multipliers for the 'health services', 'other services', and 'government services' sectors of the Australian economy.

Lastly, Generalised Estimating Equations (GEE) were used to explore the contemporaneous and one-year lagged relationships between energy prices and ambulance service performance measures. Data included 2001-2010 resource, operational and safety performance measures for all Australian ambulance services, as well as state average diesel prices, world crude oil prices, and electricity prices.

Results:

Thirty-two relevant publications were identified by the literature search. On a per-patient or per-event basis, health-related energy consumption and greenhouse gas emissions are quite modest; in the aggregate, however, they are substantial. In England and the United States, health-related emissions account for 3% and 8% of total national emissions, respectively.

The inventoried emissions of the participating Australian ambulance agencies totalled 67,390 t of CO_2e, or 35 kg CO_2e per ambulance response, 48 kg CO_2e per patient transport, and 5 kg CO_2e per capita. Vehicle fuels accounted for 58% of emissions from ground ambulance operations, with the remainder primarily attributable to electricity consumption. Emissions from air ambulance transport were nearly 200 times those for ground ambulance transport. Emissions from the direct and purchased energy consumption of all Australian ambulance operations are estimated at between 110,000 and 120,000 t of CO_2e annually.

The complete life cycle emissions of Australian ambulance services are estimated at between 216,000 and 547,000 t CO_2e annually, with approximately 20% arising from direct consumption of vehicle and aircraft fuels, 22% arising from electricity consumption, and 58% arising from upstream processes. The estimates vary substantially depending on the extent to which inventory-based versus input-output-based data are incorporated into the estimates, and whether ambulance services' economic structures are presumed to resemble those of the health, other services, or government services sector. Emissions from ambulance services represent between 1.8% and 4.4% of total Australian health sector emissions. As ambulance service expenditures represent 1.7% of total health expenditures, all except the most conservative estimates suggest ambulance services disproportionately contribute to Australian health sector emissions.

Energy conservation is also an economic issue for Australian ambulance systems. There is an association between energy prices and Australian ambulance service resource, operational and safety performance characteristics. Diesel prices and oil prices have an inverse relationship with expenditures per response and employees per 10,000 responses; that is, higher energy costs are associated with diminished resource allocation. There is a one-year lagged association between increasing diesel and oil prices and increasing median ambulance response times, and a contemporaneous association between higher electricity costs and increasing injury compensation claims.

Conclusions:

These data demonstrate that Australian ambulance services produce meaningful amounts of greenhouse gas emissions. In terms of the emissions from the direct and purchased energy consumption that are most easily influenced by EMS systems, consumption of vehicle fuels is the primary contributor to the carbon footprint of Australian ambulance systems, but electricity consumption is responsible for a substantial portion of their emissions. Efforts to minimise the carbon footprint of Australian ambulance services and ensure their environmental sustainability should target both of these energy sources.

The complete life cycle emissions of Australian ambulance services account for between 1.8% and 4.4% of total Australian health sector emissions. Ambulance services could make a meaningful contribution in efforts to reduce health sector emissions—which could be both an opportunity and a threat. As nearly 60% of ambulance service complete life cycle emissions arise from upstream supply chain processes, implementing environmentally friendly purchasing practices would be required to achieve substantial reductions in the complete life cycle emissions of ambulance services. The upstream products and services that contribute most to the complete life cycle emissions of ambulance services include some products and services that are not intuitively linked to ambulance services.

Finally, there are both environmental and economic aspects to the ‘sustainability’ of Australian ambulance operations. Energy costs have measurable

impacts on ambulance service resource, operational, and safety performance measures that could affect both patient care and employee well-being. Managing ambulance system greenhouse gas emissions is managing energy consumption, and vice-versa. It is a ‘win-win’ situation.

Key Words

Emergency Medical Services; Ambulances; Transportation of Patients; Greenhouse Gases; Carbon Footprint

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Abbreviations and Acronyms used in the Body of this Thesis

1 Lag	prior year
ACT	Australian Capital Territory
AEMO	Australian Energy Market Operator
AIP	Australian Institute of Petroleum
AvgSal	average salary
CAA	Council of Ambulance Authorities
CFC	chlorofluorocarbon
CH_4	methane
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
Comp/FTE	injury compensation claims per 100 full time equivalent employees
Comp/Resp	injury compensation claims per 10,000 responses
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Diesel$	diesel price (in Australian cents per litre)
EHS	emergency health services
EIA	Energy Information Administration
EIO-LCA	Environmental Input-Output Life Cycle Analysis
Elect$	electricity price (in Australian dollars per megawatt hour)
EMS	emergency medical services
EPA	Environmental Protection Agency
Exp/Resp	expenditures per response
FCV	(hydrogen) fuel cell vehicle
FGF	fresh gas flow
FTE	full time equivalent employees
FTE/Resp	full time equivalent employees per 10,000 responses
g	gram
GEE	generalised estimating equations
GJ	gigajoule
GNE	gross national expenditure
GNT	gross national turnover

Gv	government services economic sector
GWP	global warming potential
GWP_{20}	20 year global warming potential
H1	hybrid approach 1
H2	hybrid approach 2
H_2O	water
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
hr	hour
HREC	Human Research Ethics Committee
Hs	health services economic sector
IEA	International Energy Agency
I-O	input-output analysis
IPCC	Intergovernmental Panel on Climate Change
IQR	inter-quartile range
ISO	International Organisation for Standardisation
kg	kilogram
km^2	square kilometre
kWh	kilowatt hour
L	litre
L:TRatio	labour-to-total expenditure ratio
LCA	life cycle analysis
LP	liquefied petroleum
m^2	square metre
min	minute
Mt	million tonnes
MAS	Metropolitan Ambulance Service
MeSH	medical subject heading
N_2O	nitrogen oxide
NHS	National Health Service
NOAA	National Oceanic and Atmospheric Administration
NSW	New South Wales
NT	Northern Territory
Oil$	oil price (in Australian dollars per barrel)

Os	other services economic sector
p	probability
PFC	perfluorocarbon
ppm	parts per million
QLD	Queensland
QRV	quick response vehicle
RAV	Rural Ambulance Victoria
RT90ile	90th percentile response time
RTMed	median response time
RTQual	response time quality score
RW	reject water
S1	Scope 1
S2	Scope 2
S3	Scope 3
SA	South Australia
SDC-SEI	Sustainable Development Commission–Stockholm Environment Institute
SDU	Sustainable Development Unit
t	tonne
TAS	Tasmania
TBL	triple bottom line
TGP	terminal gate price
U.K.	United Kingdom
U.S.	United States
VIC	Victoria
WA	Western Australia
WEO	World Energy Outlook

Prologue

“You could be good at this, but if you’re not even going to try, then get out of my classroom!”

I was a 21 year old rookie police officer, 6’3” and well over 100 kg; Annice Peckham was about 52 years old, a short, scrawny red-headed widow weighing no more than 50 kg. She had me backed into a corner with her index finger wagging up and down only centimetres from my nose. I was new to the community and had signed up for the 110 hour Basic Emergency Medical Technician class offered by the Perquimans County Volunteer Rescue Squad as a way to meet people. Annice was the instructor, and I had just failed my second examination.

At that point, my presumed career trajectory was to work a few more years in law enforcement, return to university and finish my degree, and ultimately go to law school. I don’t know why I didn’t just walk away, but I didn’t—and, as Robert Frost said, “that has made all the difference”.

That moment set into motion a string of seemingly random events, happy accidents that have somehow conspired to create a career. Surely there was some planning and some intention along the way, but more often than not I simply happened upon an open door, curiously stumbled through, and found myself enjoying the next phase of an unlikely professional life mixing emergency care, academics and research.

More than 20 years on, I was attending the National Association of Emergency Medical Services Physicians’ annual meeting in Phoenix, Arizona. At the opening evening barbecue, a colleague with whom I had collaborated on a number of teaching and research projects introduced me to Ian Blanchard, “A young paramedic from Calgary who has some interest in research”. Ian and I filled our plates with pulled pork, coleslaw and baked beans, grabbed a couple of beers, and found seats at a nearby table.

The rapport was immediate, and through the course of winding and disjointed conversation we eventually landed on an area of mutual interest—the environmental and economic sustainability of Emergency Medical Services (EMS) systems. “Absolutely”, I encouraged him. “We could easily pull together a small project and get it submitted in time for presentation at next year’s annual meeting”.

The following year we presented a poster titled, “Carbon Footprinting of EMS Systems: Proof of Concept”.

Another door had opened, and again I stumbled through.

Chapter 1: Introduction and Background

1.1 Introduction

I am not an economist or an environmentalist. I am a paramedic; a clinician. But I am a clinician with a realistic perspective on how extrinsic factors can significantly impact all health-related services, no matter how important and sacrosanct we believe them to be.

The reality is that energy, specifically energy from fossil fuels, is going to become increasingly scarce and expensive. Another reality is that political and social pressures to constrain greenhouse gas emissions are going to intensify. Energy scarcity, energy costs and emissions constraints are potential threats to all industries, enterprises, organisations and services—including healthcare. Ground and air ambulance services, or Emergency Medical Services (EMS), are a vehicle-intense sector of healthcare and, as such, are particularly vulnerable to these inter-related threats. To be successful, strategies for mitigating these threats to EMS operations must be based on and supported by sound evidence (Figure 1.1). Understanding the energy and environmental burden of ambulance systems, and how these external threats manifest within those systems, is a first step towards establishing that evidence base.

This thesis thus *begins* to answer the question: How can Australian EMS systems be sustained in an economic, political, and social environment in which energy is increasingly scarce and costly, and energy consumption is increasingly constrained due to concerns about greenhouse gas emissions? It does this by: 1) reviewing the extant literature on greenhouse gas emissions from health-related activities; 2) determining the greenhouse gas emissions associated with the direct and purchased energy consumption of EMS activities; 3) estimating the complete life cycle emissions of Australian ambulance operations, including the upstream emissions arising from products and services in the supply chain; and 4) demonstrating the impact of energy price fluctuations on EMS operations.

This is the commencement—not the culmination—of an effort to ensure the sustainability of EMS systems.

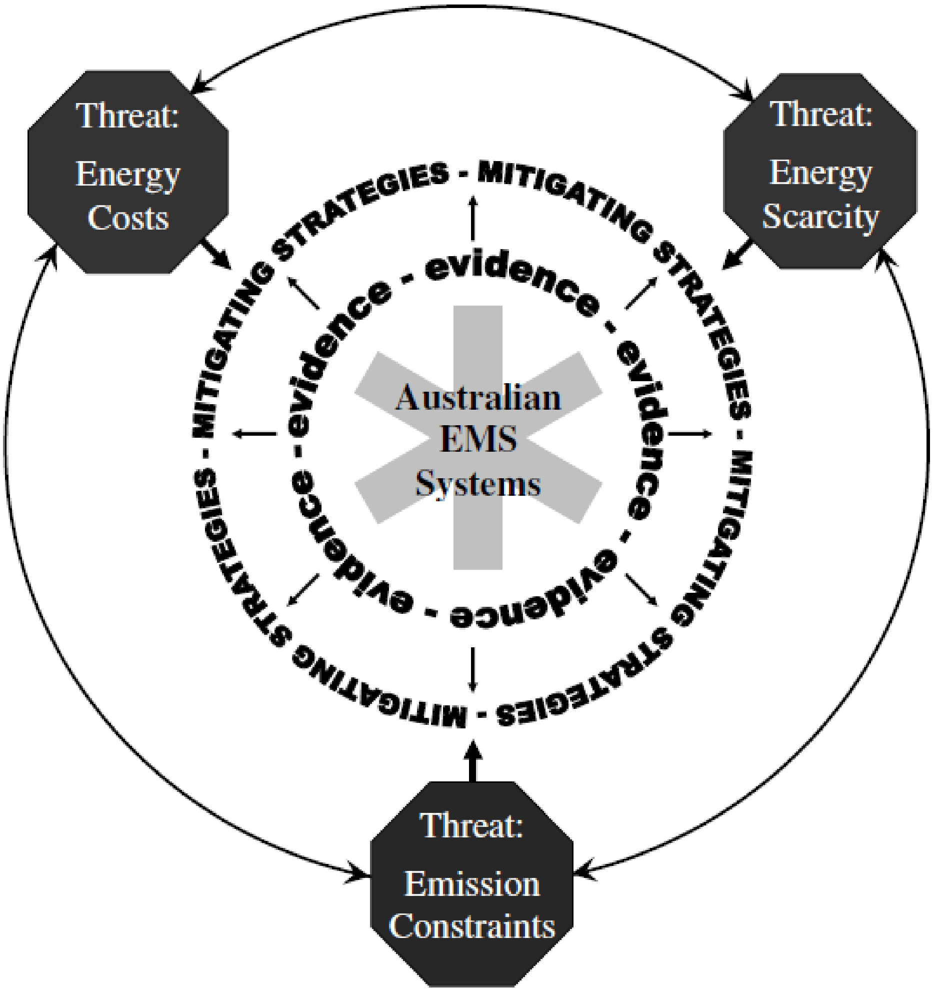


Figure 1.1: Mitigating the potential energy and environmental threats to Australian EMS systems.

1.2 Background

1.2.1 Emergency Medical Services

Internationally, ‘EMS’ is probably the most widely recognised name for what are also known as ‘ambulance services’ in the United Kingdom (U.K.) and Australia, and ‘Emergency Health Services’ (EHS) in Canada. While ambulance transport is one facet of EMS systems, their primary mission is to deliver high-quality medical care to patients at the scene of an emergency. EMS systems are part emergency service, part medical care, part public health, part community or social service, and (only) part transportation service (Brown & Devine, 2008; Delbridge et al., 1998; Garrison et al., 1997; Mann & Hedges, 2002).

For Australia’s 22 million inhabitants (and visitors), ‘ambulance services’ are delivered as a public good by the eight State and Territory governments, either through a government department or through a subcontract with St. John Ambulance, a private not-for-profit organisation. In the 2009-2010 financial year, Australian ambulance services mounted 3.5 million emergency and non-emergency responses, and transported 2.8 million patients. Operating costs for that year exceeded $2.1 billion (Council of Ambulance Authorities, 2010).

EMS systems save lives. Out-of-hospital cardiac arrest survival rates improve significantly when systems are optimised for rapid response and EMS personnel are equipped with cardiac defibrillators (Stiell et al., 1999). Patients having difficulty breathing have better outcomes when emergency personnel can give ‘breathing treatments’ and other respiratory medications (Stiell et al., 2007). Victims of car crashes and other trauma have higher survival rates when communities have cohesive trauma systems, including well developed EMS systems (Liberman, Mulder, Jurkovich, & Sampalis, 2005; Moore, Hanley, Turgeon, & Lavoie, 2010; Schiller et al., 2009).

Ground and air EMS systems are a critical component of the public health infrastructure: EMS is the intersection of public safety, public health, and health care systems (Delbridge et al., 1998). On the surface, the holistic public health perspective of health as "…a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Grad, 2002, p. 984) may seem nearly antithetical to the episodic, emergent, patient-based nature of EMS. In fact, however, "EMS professionals see firsthand—in people's bedrooms and living rooms, in their cars and in their workplaces, in neighbourhoods and communities—the interactions between individuals, their health, economic and social circumstances, community structure and resources, and environmental factors" (Brown & Devine, 2008, p. 109). As a result, EMS systems can play an important role in a number of public health activities, including elder issues (Shah, Lerner, Chiumento, & Davis, 2004; Weiss, Ernst, Miller, & Russell, 2002), disease prevention (Lerner, Fernandez, & Shah, 2009) and disease surveillance (National Highway Traffic Safety Administration, 2007), injury prevention (Garrison et al., 1997), and others.

1.2.2 Are EMS Systems Vulnerable?

Sustaining EMS systems does not merely mean continuing to provide emergency services. Indeed, it is unlikely that either economic or environmental pressures would lead to a complete shutdown of ambulance operations in any community. In this sense, sustaining EMS systems means continuing to provide both the *quantity* and *quality* of services necessary to meet the public health and medical care needs of the community. Administrative activities, recruiting and hiring, professional development education for clinicians, and equipment maintenance are just a few examples of non-patient care activities that might be viewed as 'non-essential' and thus subjected to rationing as a result of constraints on energy consumption. Yet, all of these activities, and others, are ultimately necessary to sustain the full spectrum of EMS activities, including the delivery of high-quality patient care (Lerner, Nichol, Spaite, Garrison, & Maio, 2007).

Given the importance of EMS systems, it might be hard to imagine that there would be any doubt about their sustainability; surely communities would always ensure the availability of emergency ambulance services. Around the globe, however, the lay media regularly report cuts in ‘essential’ public services, such as: police and fire departments (Armstrong, 2009; Booth, 2010); mental health services (Styles, 2009); community-based HIV and AIDS service organisations (Canadian News Wire, 2009); parks and recreation services, community centres, and even streetlights (Booth, 2010). The medical literature also contains reports of reductions in health services and closures of hospitals, and of the impacts of those decisions on patients and communities (Jackson & Whyte, 1998; Probst, Samuels, Hussey, Berry, & Ricketts, 1999; Reif, DesHarnais, & Bernard, 1999), including some reports from Australia (Farhall, Trauer, Newton, & Cheung, 2003; Fraser, 2004). Nothing is sacrosanct.

This research focuses specifically on threats to EMS systems posed by energy scarcity, energy costs, and constraints on greenhouse gas emissions (Figure 1.1 above). As the following sections demonstrate, these are not simply theoretical concerns.

1.2.2(a) Energy Scarcity

In 2008, delivery of diesel and gasoline to parts of the south-eastern United States (U.S.) was interrupted resulting in widespread fuel shortages (Associated Press, 2008; Stock & Siceloff, 2008). Although there were no published reports of disruptions to direct patient care services, some EMS operations were affected in other ways. In metropolitan Atlanta, Georgia, ambulances had to source fuel from alternative suppliers (Hess and Greenberg, 2011); one system in North Carolina had to suspend community and employee educational programs (personal communication, S. Hawkins, Burke County N.C. EMS).

While episodic local, regional and national variations in energy supplies are an immediate energy threat to EMS systems, global energy scarcity is a more challenging and longer-term threat. The concept of 'peak oil' was first proposed by M. King Hubbert in the 1950s, referring specifically to the anticipated peak for oil production in the continental U.S. (Hubbert, 1956). The prediction was that oil production would reach a pinnacle, and then decline rapidly. For the U.S., that peak occurred in the 1970s with continuing energy demands met through importation of foreign oil. The concern now is for global peak oil, when it will occur or if it already has (Aleklett et al., 2010; Schnoor, 2007; Sorrell, Speirs, Bentley, Brandt, & Miller, 2010; Verbruggen & Al Marchohi, 2010), and how that will directly and indirectly affect public health and health services (Frumkin, Hess & Vindigni, 2007, 2009; Hanlon & McCartney, 2008; Hess, Heilpern, Davis, & Frumkin, 2009; Wilkinson, 2008).

Persistent fuel shortages would impact both the breadth of services and quality of patient care delivered by EMS systems.

1.2.2(b) Energy Costs

Throughout the developed world, EMS operations struggled to continue service delivery during the dramatic fuel price increases experienced in 2007 and 2008. For example, in British Columbia, Canada, price increases added $6 million to the fuel costs of the ambulance service, a 50% increase that had not been budgeted (Penner, 2008). In the U.S., one private corporation providing air medical services and aircraft resources in

44 states saw its earnings per share fall nearly 37% (Harlin, 2009). While neither of these operations ceased providing emergency services, financial resources had to be redirected from other activities to accommodate these fiscal insults.

A persistent need to divert resources to accommodate increased energy costs would also impact both the breadth of services and quality of patient care delivered by EMS systems.

1.2.2(c) Constraints on Greenhouse Gas Emissions

While it has received much more attention in recent years, global warming is not a new concern. Since the late 1980s there have been reports of increasing global surface temperatures amounting to 0.5^{o}C over the 130 years between the 1850s and 1980s (Piver, 1991). Current estimates are that, even with concerted efforts to address climate change, global surface temperatures will continue to increase to somewhere between 2^{o}C to 2.5^{o}C above pre-industrial levels (Allen et al., 2009; Ramanathan & Feng, 2008).

Political and social pressures to constrain greenhouse gas emissions will likely intensify and, although less certain, increasing legislative and regulatory constraints on emissions are possible. On an international basis, efforts to restrain and reduce carbon dioxide (CO_2) and other greenhouse gas emissions are escalating. Building on the experience of the Montreal Protocol, which resulted in significant reductions in the chlorofluorocarbons (CFCs) responsible for ozone depletion (Velders, Andersen, Daniel, Fahey, & McFarland, 2007), the Kyoto Protocol and the more recent Copenhagen Accord seek to limit greenhouse gas emissions and eventually reduce them to pre-1990 levels. While the details of the limits and mechanisms for accounting continue to be debated, there is extensive commitment to the concept with 187 countries having signed and ratified the Kyoto Protocol, and 188 nations supporting the Copenhagen Accord (Ramanathan & Xu, 2010).

Ambulance operations are motor vehicle—and aircraft—dependent; intensifying efforts to constrain greenhouse gas emissions threatens both the breadth and quality of services provided by EMS operations.

1.3 Specific Aims

How can Australian EMS systems be sustained in an economic, political, and social environment in which energy is increasingly scarce and costly, and energy consumption is increasingly constrained due to concerns about greenhouse gas emissions? This research includes four specific aims that will help begin to answer that question by quantifying the greenhouse gas emissions produced by Australian EMS systems, identifying the energy sources and production processes that contribute most to Australian ambulance service emissions, and determining how energy costs affect Australian ambulance operations:

Specific Aim #1: Review the extant literature on the energy consumption and the environmental impact of health services.

Specific Aim #2: Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

Specific Aim #3: Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute most to those emissions.

Specific Aim #4: Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

Figure 1.2 shows the relationships between the specific aims.

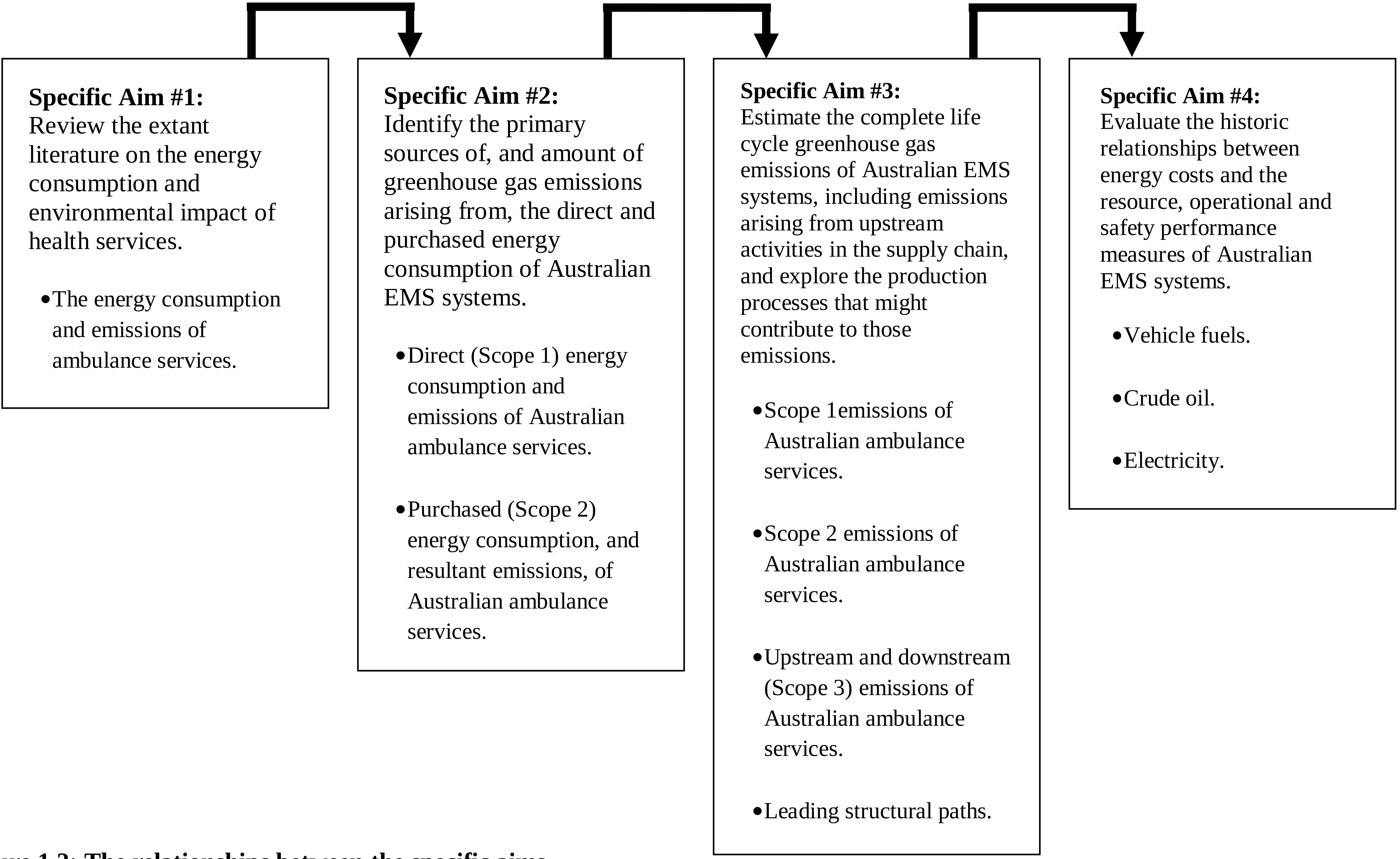
1.4 Assumptions

There are a number of assumptions underpinning these specific aims, and these are explicitly stated here. This thesis does not test these assumptions:

- EMS systems are an integral component of the public health system, and have a positive impact on health at both the population and individual patient levels (Delbridge et al., 1998; Garrison et al., 1997; Liberman, Mulder, Jurkovich, & Sampalis, 2005; Mann & Hedges, 2002; Schiller et al., 2009; Stiell et al., 1999; Stiell et al., 2007).

- All of the components of EMS systems are necessary to meet their public health and patient care objectives (Lerner, Nichol, Spaite, Garrison, & Maio, 2007).

- Mounting energy scarcity, increasing energy costs, and intensifying constraints on greenhouse gas emissions are imminent (Aleklett et al., 2010; Ramanathan & Xu, 2010; Sorrell, Speirs, Bentley, Brandt, & Miller, 2010; Verbruggen & Al Marchohi, 2010).



Specific Aim #1:
Review the extant literature on the energy consumption and environmental impact of health services.

- The energy consumption and emissions of ambulance services.

Specific Aim #2:
Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

- Direct (Scope 1) energy consumption and emissions of Australian ambulance services.
- Purchased (Scope 2) energy consumption, and resultant emissions, of Australian ambulance services.

Specific Aim #3:
Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute to those emissions.

- Scope 1emissions of Australian ambulance services.
- Scope 2 emissions of Australian ambulance services.
- Upstream and downstream (Scope 3) emissions of Australian ambulance services.
- Leading structural paths.

Specific Aim #4:
Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

- Vehicle fuels.
- Crude oil.
- Electricity.

Figure 1.2: The relationships between the specific aims.

- EMS systems are not impervious to mounting energy scarcity, increasing energy costs or intensifying constraints on greenhouse gas emissions (Associated Press, 2008; Harlin, 2009; Hess & Greenberg, 2011; Penner, 2008; Stock & Siceloff, 2008).

- EMS systems can adapt to the evolving economic, political, and social environment; that adaptation will be better if it is driven by evidence.

1.5 Significance

Ultimately, the results of this work can be used to help ensure both the economic and environmental sustainability of Australian EMS systems, including the full range of non-patient-care activities required to support high-quality service delivery. In the short run, ambulance systems might be able to reduce administrative or ancillary activities to accommodate constraints on energy consumption, energy expenditures or greenhouse gas emissions; in the long run reductions in those support activities would eventually begin to compromise patient care. Equipping systems and their leaders with empirical data regarding EMS energy consumption and greenhouse gas emissions will enable them to better respond to public policy initiatives designed to constrain or reduce emissions, as well as to better manage diminished fuel availability or increasing energy costs. The likely (and optimal) strategies for managing EMS-related energy consumption and emissions are yet to be determined. It is unlikely that any single strategy will work for all systems; some seemingly intuitive strategies might not fully achieve the anticipated results, or indeed they might actually have detrimental effects—phenomena known respectively as ‘rebound’ and ‘backfire’ (Druckman, Chitnis, Sorrell, & Jackson, 2011; Hanley, McGregor, Swales, & Turner, 2009). Future work evaluating potential energy- and emission-mitigating strategies is crucial to ensure that any actions taken have the desired impact.

With improved knowledge of the greenhouse gas emissions associated with EMS operations and the potential targets for emission mitigating strategies, EMS systems can begin to develop and implement policies aimed at reducing their carbon footprint. In the U.S. it is estimated that up to 20 million ambulance transports occur each year (Nawar, Miska, & Xu, 2007). In Australia, the number of ambulance responses and transports is smaller (in the order of 3 million), but many involve patients in remote settings necessitating transport over longer distances, and often requiring air medical transport. Given the scope of EMS operations on a global scale, even marginal reductions in the emissions from each individual ambulance response could result in significant overall reductions of greenhouse gas emissions.

There are also additional benefits to minimising EMS-related emissions, as their effects have both direct and indirect impacts on EMS. Vehicle emissions are associated with ill-health, particularly (and ironically) cardiac and respiratory diseases responsible for many EMS responses (Gallagher et al., 2010; Jerrett et al., 2008; McConnell et al., 2006; Medina-Ramon, Goldberg, Melly, Mittleman, & Schwartz, 2008; Modig et al., 2006). This is also an occupational health issue; although modern engines produce fewer pollutants, diesel fumes have been implicated in some respiratory problems experienced by emergency personnel (Gately & Lenehan, 2006).

Further, while the current popular emphasis might be on reducing EMS-related greenhouse gas emissions and their contribution to global warming, the real ‘win’ from managing those emissions is likely to be a reduction in energy consumption, and thus energy costs. With improved knowledge of the predominant energy burdens of EMS systems, the relative energy demands of different EMS delivery models can be considered when developing and revising system operational models, and policies can be designed and implemented to reduce energy consumption and energy-related costs.

1.5.3 Potential Broader Impact

The results of this work, while specific to Australian EMS systems, could also prove beneficial to EMS operations in other countries as well as to other areas of public health. There is increasing interest in the emissions associated with health activities (Anonymous, 2008; Bayazit & Sparrow, 2010; Blakemore, 2009; Blanchard & Brown, 2009; 2011; Callister & Griffiths, 2007; Chung & Meltzer, 2009; Creagh, 2008; Gilliam, Davidson, & Guest, 2008; Hudson, 2008; Mayor, 2008; McMichael & Bambrick, 2007; Roberts & Godlee, 2007; Somner, Scott, Morris, Gaskell, & Shepherd, 2009; Somner et al., 2008), and this work could contribute to those efforts. The results of this work could also inform broader economic and environmental efforts related to the sustainability of health care systems, serving as a foundation for future studies. Although it is not the focus of this work, the methods developed and findings could be particularly useful in efforts to develop health services—particularly ambulance services—in resource poor environments, where energy scarcity is already impeding public health.

The relationships between the environment, economic forces, and health services are multifaceted and often unclear. Figure 1.3 is a hypothetical representation of the complex theoretical interactions between the environmental, economic and public health benefits of reducing EMS-related energy consumption, energy expenditures and greenhouse gas emissions.

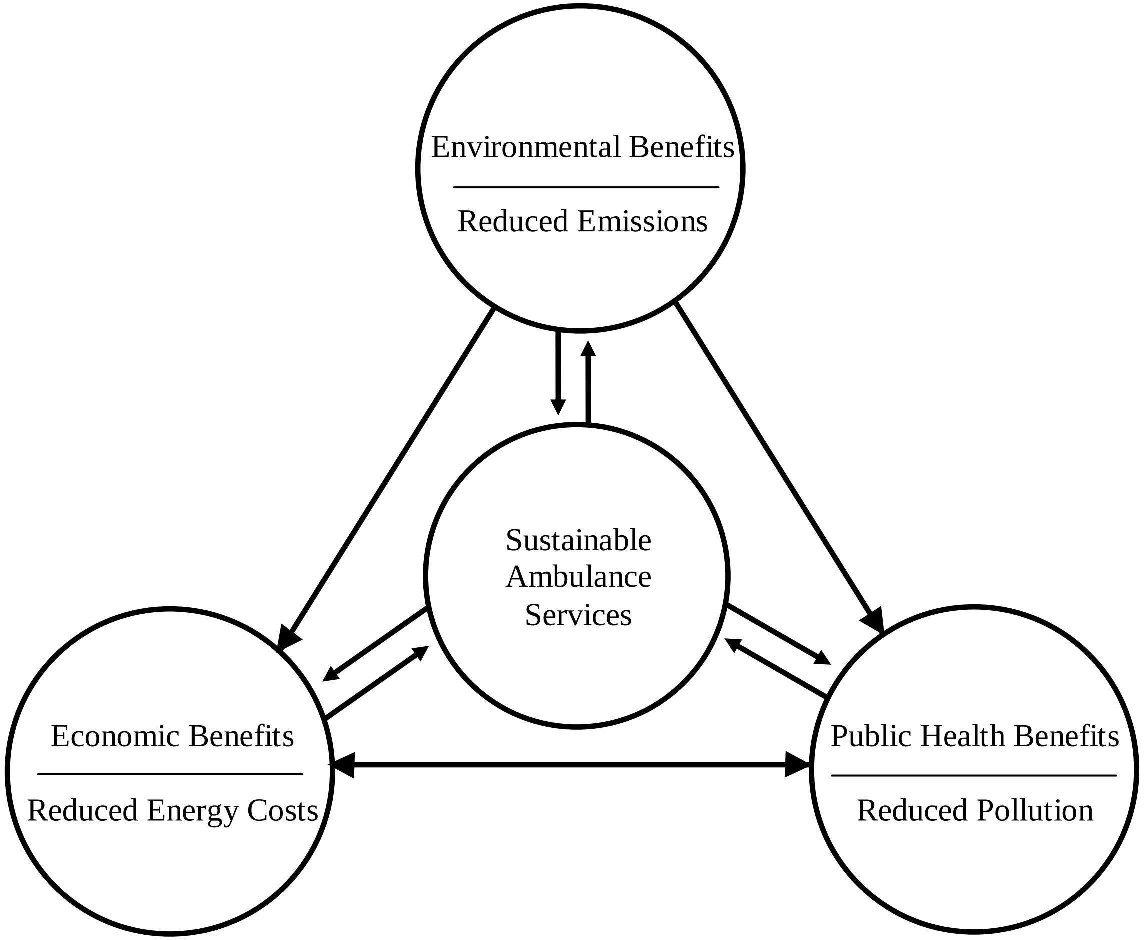


Figure 1.3: The complex theoretical interactions between the economic, environmental and public health benefits of reducing EMS-related energy consumption and greenhouse gas emissions.

Chapter 2: Theoretical and Methodological Framework

This chapter lays out the theoretical and empirical bases for climate change, energy scarcity and energy costs, and reviews the methodological approaches to inventorying energy consumption and greenhouse gas emissions.

2.1 Climate Change

2.1.1 Atmospheric Temperatures Are Increasing

In the late 1980s Hansen & Lebedeff (1987; 1988) analysed monthly surface air temperature data from three partially overlapping data sources: the U.S. National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration (NOAA) “Monthly Climatic Data of the World” and the NOAA monthly mean station records. They found the 1980s to be the warmest decade in the history of instrument-measured temperatures, with the four warmest years on record occurring in that decade (Hansen & Lebedeff, 1987; 1988). They also found that the rate of warming between the mid-1960s and late 1980s was greater than that which occurred between the 1880s and 1940s. After correcting for ‘heat island’ effects of increasing urbanisation, they estimated the 1987 global surface temperature was 0.63 ± 0.2^{o}C warmer than in 1880 (Hansen & Lebedeff, 1988).

Using completely different methods, Urban, Cole & Overpeck (2000) reached remarkably similar conclusions. They evaluated core samples from coral growing on the outer reef at Maiana Atoll in Kiribati using mass spectrometry with the isotope $\delta^{18}O$ to create a 155-year climate record dating from 1840 to 1995. They found a trend towards increasingly warmer and wetter conditions spanning the full record, with gradual increases in the early twentieth century followed by abrupt changes after 1976. Further, they found increasing climate volatility, with climate variability occurring primarily on a decadal scale in the early record, but on a mainly inter-annual scale in the twentieth century.

Increasing surface temperatures continued through the 1990s and early 2000s. In the 4th report of the Intergovernmental Panel on Climate Change (IPCC), the “Physical Science Basis” working group reviewed data from four distinct evaluations, finding that between 1979 and 2005 mean surface temperatures increased between 0.19 ± 0.07°C to 0.32 ± 0.09°C per decade, with the differences in estimations attributed primarily to differences in approaches to spatial averaging (Solomon et al., 2007).

2.1.2 Greenhouse Gases Collect in the Atmosphere

‘Greenhouse gases’ are components of the Earth’s atmosphere that allow light to easily penetrate the atmosphere and warm the planet’s surface; they also absorb, hold and re-emit heat in the form of infrared radiation. As shown in Table 2.1, there are dozens of greenhouse gases, many of which occur naturally in the environment (Bera, Francisco, & Lee, 2009).

Table 2.1: Some common greenhouse gases (adapted from Bera, Francisco, & Lee, 2009).

Carbon Dioxide	Water Vapour	Chloroform	Sulphur Hexafluoride
Nitrous Oxide	HFC-32	Carbon Tetrachloride	Sulphur Dioxide
Methane	HFC-23	HCFC-22	Phosphine
Methyl Fluoride	PFC-14	Ammonia	Triflourophosphine
Methyl Chloride	CFC-13	Nitrogen Trifluoride	
Methylene Chloride	CFC-12	Oxygen Difluoride	
Methyl Bromide	CFC-11	Ozone	

CFC – chlorofluorocarbon; HFC – hydrofluorocarbon; HCFC – hydrochlorofluorocarbon; PFC – perfluorocarbon

Greenhouse gases are not inherently bad. As Grenfell et al. (2010, p. 77) explain, “Without greenhouse-like conditions to warm the atmosphere, our early planet would have been an ice ball, and life may never have evolved”. The atmosphere as we know it today is the product of complex interactions between early bacterial life forms that produced and consumed oxygen, photosynthesis, and greenhouse effects (Grenfell et al., 2010).

Different greenhouse gases have different heat absorbing, holding and emitting characteristics and thus different ‘global warming potentials’ (GWP) (Bera, Francisco, & Lee, 2009; Hansen et al., 1998). CO_2 is the most abundant of the greenhouse gases, and is the reference against which other greenhouse gases are measured. CO_2 has a GWP of 1, and other greenhouse gases are measured as CO_2 equivalents (CO_2e). Methane (CH_4), for example, has a GWP about 25 times that of CO_2, or a GWP of 25 CO_2e (Bera, Francisco, & Lee, 2009).

Atmospheric levels of CO_2 have risen steadily over the last millennium. For the pre-industrial timeframe, spanning the years 1000 to 1750, the IPCC estimates atmospheric CO_2 concentrations ranged between 275 to 285 parts per million (ppm) (Solomon et al., 2007). In the industrial age, atmospheric CO_2 concentrations have risen dramatically. Piver (1991) cites data from the Mauna Loa Observatory in Hawaii showing an increase in atmospheric CO_2 concentrations from approximately 316 ppm in 1958 when the first measurements were made to 347 ppm in 1986. In 2005, atmospheric CO_2 concentrations reached 379 ppm (Solomon et al., 2007), and in 2010 concentrations as high as 390 ppm were measured at the Mauna Loa Observatory (National Oceanic and Atmospheric Administration, 2010).

2.1.3 The Association between Rising CO_2 Levels and Increasing Temperatures is Probably more than Coincidence

Rising surface temperatures and increasing atmospheric CO_2 levels could co-exist without one necessarily causing the other. There is some probability that the association is simply a function of chance, but that probability is small.

Genthon et al. (1987) have made estimates of historic temperatures and atmospheric CO_2 levels going back 160,000 years by analysing air trapped in the Vostok ice core from Antarctica. They conducted multivariable analysis examining the relationship between the Vostok isotope temperature record and climatic inputs including southern hemisphere ‘insolation’ (solar radiation of the Earth’s surface, also referred to as ‘orbital forcing’), northern hemisphere insolation, ocean ice volume estimated by the $\delta^{18}O$ deep sea record, and CO_2 levels. The various models analysed achieved high correlation, with r^2 values ranging from 0.84 to 0.90. While measures of insolation were associated with temperature increases, when holding the southern hemisphere inputs constant and evaluating northern hemisphere forcing “[t]he common feature of all these analyses [was] that the main contribution [came] from CO_2…” (Genthon et al., 1987, p. 416). Modifying the timescale to put it in phase with historic sea surface temperatures around Antarctica, or limiting the analysis to the most recent 100,000 years, did not significantly change the results. Two models, both using the $\delta^{18}O$ ice volume record (instead of insolation) as the northern hemisphere input, did result in less pronounced associations between CO_2 levels and the measured temperature change, but CO_2 levels still accounted for 27% to 35% of the temperature variance in both of those models.

The authors concluded that the maximum influence of southern hemisphere insolation inputs on temperature change is 20%, northern hemisphere inputs only predominate when the ice volume record is the basis for estimates, and the relative contributions of CO_2 to temperature changes exceed 50%—and are as high as 84%—except for when ice volume is used as the northern hemisphere input. They asserted that "… the Vostok series appear to provide the most direct support so far of … an interaction between CO_2, orbital forcing and climate…" (Genthon et al., 1987, p. 418) but they also caution that extrapolating analyses of past conditions to present day or future impacts of CO_2 would require a better understanding of the mechanisms involved in this interaction.

2.1.4 Human Activity Produces Greenhouse

Human activity produces CO_2 and other greenhouse gases. The greatest source of these 'anthropogenic' emissions is the burning of fossil fuels including coal, oil and its derivatives, and natural gas. The most abundant greenhouse gases influenced by human activity are CO_2, CH_4, nitrogen oxide (N_2O) and CFC 11 and 12 (Hansen et al., 1998). The concern about anthropogenic greenhouse gases is not that they exist and accumulate in the atmosphere, but rather the increasing levels at which they exist and are accumulating in the atmosphere.

2.1.5 The Association between Rising CO_2 Levels and Human Activity is Probably more than Coincidence

Natural processes, such as volcanoes, also produce greenhouse gases, and—as with all things in nature—there is inherent variation in atmospheric CO_2 levels. It is difficult, however, to ascribe recent atmospheric CO_2 concentrations approaching 400 ppm to natural processes and inherent variation alone. For example, in the CO_2 record of the Vostok ice core, at no point did historic CO_2 levels exceed 300 ppm, and to find

CO_2 concentrations exceeding 275 ppm requires looking back more than 115,000 years (Barnola, Raynaud, Korotkevich, & Lorius, 1987).

The predominant scientific and political consensus is that human activity, rising CO_2 levels and increasing temperatures are all inter-related. While the 15th Conference of the Parties of the United Nations Framework Convention on Climate Change, held in Copenhagen, Denmark in December 2009, failed to achieve agreement on how to mitigate climate change, all but five of the 193 participating nations supported the 'Copenhagen Accord'. The opening paragraph of the Accord states, "We underline that climate change is one of the greatest challenges of our time" and the second paragraph follows with, "We agree that deep cuts in global emissions are required…" (Ramanathan & Xu, 2010, p. 8055). A lack of agreement on how to mitigate climate change is not a lack of agreement about the relationship between anthropogenic greenhouse gases, rising atmospheric CO_2 levels, and global warming. Even with concerted efforts to reduce greenhouse gas emissions, global surface temperatures will likely continue to increase to between $2^{o}C$ to $2.5^{o}C$ above pre-industrial levels (Allen et al., 2009; Matthews, Gillett, Stott, & Zickfeld, 2009; Ramanathan & Feng, 2008). An increase as large as $3.9^{o}C$ to $4.3^{o}C$ above pre-industrial levels is within the 95% confidence intervals for these estimates (Allen et al., 2009; Ramanathan & Feng, 2008).

2.1.6 A Caveat: Nothing is Absolute

It is important to recognise that the relationships between human activity, greenhouse gas emissions and rising temperatures are neither simple nor isolated. Rising CO_2 levels and increasing temperatures are not exclusively attributable to human activity (Hansen et al., 1998; Raschke, 2001) and some emissions from human activity—for example, aerosols and anthropogenic clouds (e.g., aircraft contrails)—

actually have a cooling effect (Hansen et al., 1998; Ramanathan & Feng, 2008). Indeed, a paradox is that reducing aerosols and other atmospheric pollutants might enhance global warming.

There are also some who question the validity and reliability of climate data, climate-related analyses, and even the objectivity of the peer-reviewed literature (Robinson, Robinson, & Soon, 2007; Singer, 2003). Consensus is not 100% agreement; association is not necessarily cause-and-effect; probability is not certainty.

The United Nations Environment Programme recognises this lack of certainty, and has addressed it in the *Rio Declaration on Environment and Development* by adopting ‘Principle 15’:

> “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (United Nations Environment Programme, 1992).

Although not technically correct, this is sometimes referred to as ‘The Precautionary Principle’. Put simply, in the absence of absolutely conclusive evidence, there is greater risk in presuming rising temperatures, increasing CO_2 levels, and human activity are *not* interrelated; it is safer to trust the preponderance of the evidence and take action on the presumption that they are linked.

2.2 Energy Scarcity

Sheikh Zaki Yamani, the Saudi Arabian oil minister between 1962 and 1986, is quoted as saying, “The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil” (Wilkinson, 2008, p. 664). That prediction was about relative—not absolute—scarcity; that eventually we would consume oil faster than we could cost-efficiently pump it out of wells, and therefore we would find and develop other energy resources long before we ran out of oil.

2.2.1 Peak Oil

As mentioned in Chapter 1, the concept of peak oil was first described by M. King Hubbert in the 1950s. He predicted U.S. oil production would peak in the 1970s, and then rapidly decline. Although the high point of U.S. oil production exceeded Hubbert’s estimate by 600 million barrels per year, the peak and subsequent fall in production did in fact occur. That is, in 1970 U.S. oil production peaked at approximately 3.5 billion barrels per year; it has declined ever since and by 2007 it had dropped to less than 2 billion barrels per year (Verbruggen & Al Marchohi, 2010). Despite recent innovations in extractions from oil shale and oil sands, the concern now is about global peak oil (Aleklett et al., 2010; Sorrell, Speirs, Bentley, Brandt, & Miller, 2010; Verbruggen & Al Marchohi, 2010), and how that could affect public health and health services (Frumkin, Hess, & Vindigni, 2007; Hanlon & McCartney, 2008; Hess, Heilpern, Davis, & Frumkin, 2009; Wilkinson, 2008).

Globally, there are currently about 70,000 producing oil fields, but just 25 of these fields account for 25% of world oil production, and a mere 500 fields hold two-thirds of all cumulative oil discoveries (Sorrell, Speirs, Bentley, Brandt, & Miller, 2010). These are mostly older fields that have passed or are near their production peak

(Sorrell et al., 2010). Noting that “[a]t some point, the additional production from small fields that are discovered relatively late will become insufficient to compensate for the decline in production from large fields…” (Sorrell et al., 2010, p. 5290), scientists at the U.K. Energy Research Centre undertook a systematic review of the evidence concerning global oil depletion that included more than 500 studies, 14 global supply forecasts, and data from industry databases (Sorrell et al., 2010). They reported that the current estimate for the ultimately recoverable resources for conventional oil is between 2,000 and 4,300 billion barrels; this compares to cumulative production of 1,128 billion barrels through the end of 2007. That is, what we have already consumed is equivalent to between 25% and 50% of all currently available conventional oil. These authors reported that the average rate of decline in production from post-peak fields is 6.5% per year, with an average decline in production for all currently producing wells of 4% per year. They suggested that as much as 20 billion barrels of oil must be added to global reserves every year just to offset this decline in production. They concluded that “… a peak of conventional oil production before 2030 appears likely and there is a significant risk of a peak before 2020” (Sorrell et al., 2010, p. 5294). They further argued that “[d]elaying the peak beyond 2030 requires optimistic assumptions about the size of the recoverable resource and the rate at which it is developed…” (Sorrell et al., 2010, p. 5293).

Others are even more pessimistic. In a critical analysis of the 2008 *World Energy Outlook* (WEO), which is published each year by the International Energy Agency (IEA), Aleklett et al. (2010) evaluated the IEA estimates of future energy consumption and production through the end of year 2030. WEO 2008 estimates economic growth at 3% per year until 2015, corresponding to a 1.3% annual increase in oil consumption which then falls to 0.8% per year after that. This translates into global consumption of 106.4 million barrels of oil per day by 2030, which is 5.1 million barrels per day more than the WEO 2008 production projections for that year.

These authors also made their own estimate of year 2030 oil production, taking into consideration currently producing fields (70.2 million barrels per day in 2007) with a rate of decline of 3.2% annually, known fields yet to be developed (257 billion barrels by 2030), fields yet to be found (estimated by IEA at 114 billion barrels by 2030) and emerging innovative technologies for recovering non-conventional oils including oil sands, heavy oil from Venezuela, 'gas-to-liquids' and 'coal-to-liquids', chemical additives, and natural gas liquids. They also factored in the potential for enhanced oil recovery technologies. Still, they estimated 2030 production at only 75.8 million barrels per day—nearly 25% less than the WEO 2008 estimate (Aleklett et al., 2010).

The differences in all of these estimates are primarily attributable to the predicted *depletion rate of remaining recoverable resources.* That is, as the remaining volume of oil in any given field goes down, how much of that remaining oil can efficiently be recovered each year? This varies by type of well, and presumably new technologies will drive depletion rates higher, but the WEO 2008 estimates of future on-shore oil well depletion rates in the 9% to 15% range by 2025-2030 far exceed anything achieved so far (~2% to 7%). Thus, as Aleklett et al. (2010, p. 1412) concluded, future oil production is unlikely to meet future demand as estimated by WEO 2008; "[t]he world appears most likely to have *passed* the peak of global oil production and to have entered the descent phase" [emphasis added].

Of course, predictions of future oil supplies and production, whether optimistic or pessimistic, are inherently imperfect. They are based on "…the amount of oil that is mineable at today's prices using existing technology" (Verbruggen & Al Marchohi, 2010, p. 5576) and are subject to frequent revision. For example, IEA projections have been described as "… alternating from optimistic to pessimistic and back again" (Miller, 2011, p 1569). These variations primarily result from changes in the assumptions underlying the predictions, particularly those related to economic growth and consumption as well as technological advancements in the recovery processes (Miller, 2011; Verbruggen & Al Marchohi, 2010). Also, one cannot completely discount that political or proprietary interests might also influence the predictions.

2.2.2 Peak Minerals or Peak Resources

Oil is not the only energy source at risk of relative scarcity. More recently, authors have raised the spectre of impending 'peak coal' (Heinberg & Fridley, 2010; Mason, Prior, Mudd, & Giurco, 2011; Patzek & Croft, 2010), as well as peak production for other minerals (Mason, Prior, Mudd, & Giurco, 2011), and how that might affect electricity production. Scarcity of rare earth minerals could potentially even constrain deployment of solar- and wind-generated electricity technologies.

2.2.3 Opposing Perspectives

Not everyone accepts that peak oil (or peak minerals/resources) is inevitable. Radetzki (2010, p. 6566) cites past "[p]rophecies of impending catastrophes based on resource pessimism" and argues that since "none of them have actually occurred" human ingenuity, technical progress and competitive markets can adequately address the problem. He argues that estimates of ultimately recoverable reserves are continuously updated, and that oil fields invariably produce more oil than is estimated when they are first discovered. Radetzki (2010, p. 6569) slightly misquotes a decade-old passage by Adelman (2002) to make his point:

> “In 1944, world proved reserves were 51 billion barrels. In 1945-1998, 605 billion barrels were removed, leaving 1035 billion” (Adelman, 2002, p. 180).

However, Adelman (2002) also argued that ‘nonproved reserves’ (or fields yet to be found)…

> “…are not comparable with or additive to proved reserves. They are estimated future output from facilities not yet in being, whose costs will reflect future geology and engineering. Anyone who adds nonproved to proved reserves, and from that total predicts future output, implicitly claims to know future science and technology” (Adelman, 2002, p. 180).

Presumably, then, he would disagree with Radetzki’s reliance on anticipated future reserves and production as protection against peak oil. Indeed, Adelman didn’t argue against peak oil, but rather (much like Sheikh Yamani) predicted economic scarcity driven by constraints on production in the form of rising marginal costs, not absolute scarcity.

Verbruggen & Al Marchohi (2010) also discussed the limitations of estimating future oil production, noting that today’s technologies leave nearly two-thirds of a field’s oil in the ground. Oil shortages will likely drive up prices and spur innovation such that in the future oil field production, rate of decline, and the depletion rate of remaining recoverable resources will be more advantageous than today. They also point out that projections of peak oil are hampered by inconsistencies in the definitions used for ‘conventional oils’, ‘non-conventional oils’, ‘reserves’ and ‘resources’, and by physical, economic, and technological uncertainties—particularly in less developed nations. They do not question the concept of peak oil, but they note that current predictions are really about "…the peaking of conventional, easy-to-access 'premium' oil, not too far in the future" (Verbruggen & Al Marchohi, 2010, p. 5578). That is, a step along the way to peak oil is 'peak cheap oil'.

Economic and environmental pressures on energy consumption are also inter-related, and growing environmental concerns could suppress oil production more so than limited supply or constraints on production (Verbruggen & Al Marchohi, 2010). Thus,

> "[t]he insight is growing that we will (have to) leave many oil resources in the ground because the transition to highly efficient, renewable energy based energy economies is urgent. So a peak in oil production may actually be observed in the next decade, not because of oil reserves shortage but because of scarcity of atmospheric space for dumping carbon dioxide from oil winning and oil combustion" (Verbruggen & Al Marchohi, 2010, p. 5580).

2.3 Energy Costs

Energy scarcity is only one of the energy-related threats to health systems. Energy costs are an equally important, and potentially more pressing, concern for health services, including EMS.

2.3.1 Energy Costs and Economic Performance

Energy costs vary widely over time, and are affected by a complex and difficult to model interplay between world events, production levels, consumer demand, political sensitivities and tax policies (Gallo, Mason, Shapiro, & Fabritius, 2010; Ghoshray & Johnson, 2010; Hamilton, 1983). On a macroeconomic level, sharp increases in oil prices are a precursor to slowing in the growth of gross national product in the U.S., and have pre-dated every recession in that nation since World War II except for one (1960-1961) (Hamilton, 1983). Oil and energy price shocks, as well as price volatility, also adversely affect stock returns in market economies around the world (Faff & Brailsford, 1999; Huang, Hwang, & Peng, 2005; Jones & Kaul, 1996; Nandha & Faff, 2008; Park & Ratti, 2008; Sadorsky, 1999), although energy stocks do benefit from price shocks (El-Sharif, Brown, Burton, Nixon, & Russell, 2005; Huang, Masulis, & Stoll, 1996). The negative impacts of price shocks on stock returns are greatest for medium-sized firms (Sadorsky, 2008). Energy price increases and price volatility also negatively impact firm-level strategic investment (Henriques & Sadorsky, 2011; Yoon & Ratti, 2011). Firms that undertake sustainability initiatives, however, generally reduce their exposure to energy price fluctuations (Henriques & Sadorsky, 2010).

There is also some evidence that energy costs contribute to health care price inflation. A time series analysis of U.S. petroleum and health care prices between 1973 and 2008 found a 1% increase in oil price inflation was associated with a 0.03% increase in medical care prices after an eight month lag. This price elevation persisted for 20 months, although the effect was much stronger in the 1970s than in recent years. (Hess, Bednarz, Bae, & Pierce, 2011).

2.4 Energy Consumption and Emissions Accounting Methodologies

There are a number of approaches to energy and emissions accounting; these are described in the following sections.

2.4.1 Ecological Footprints

One measure of environmental impact is the ‘ecological footprint’, which Rees (1992, p. 121) described as “the total area of land required to sustain [a] … region”.

Ecological footprints express the consumption and waste associated with human economic activity in terms of the hectares of land required to provide the resources necessary to support that activity as well as absorb the waste generated by that activity (Kitzes & Wackernagel, 2009; Rees, 1992). It is not a perfect, universally applied metric (Moffatt, 2000; Templet, 2000; van den Bergh & Verbruggen, 1999)—for example, there is some debate as to whether an ecological footprint should be measured in terms of local hectares and thus the carrying capacity of only the land geographically proximal to the economic activity, or in terms of global hectares and thus the entire carrying capacity of the Earth (Wackernagel, Monfreda, Erb, Haberl, & Schulz, 2004; Wiedmann & Lenzen, 2007). Still, conceptually the ecological footprint is seen as at least a useful metaphor in sociological and political discussions (Opschoor, 2000; van Kooten & Bulte, 2000), and environmentalists and ecologists continue to use and improve the measure to describe the sustainability of human activities (Kitzes et al., 2009; Wackernagel, 2009). It has been used in studies evaluating the environmental burden of, for example, the New Zealand economy (Bicknell, Ball, Cullen, & Bigsby, 1998), academic departments within a University (Wood & Lenzen, 2003), the economies of Austria, the Philippines and South Korea (Wackernagel et al., 2004), the province of Siena, Italy (Bagliani, Galli, Niccolucci, & Marchettini, 2008) and grain consumption in Israel (Kissinger & Gottlieb, 2010).

2.4.2 Carbon Footprints

Recently, the term ‘carbon footprint’ has gained colloquial traction as a moniker for the environmental impact of an entity or activity. ‘Carbon footprint’ is likely derived from the term ‘ecological footprint’ (Matthews, Hendrickson, & Weber, 2008). Although it has no universally accepted definition, generally a carbon footprint is an accounting of the CO_2 and other greenhouse gases emitted by an organisation over some period of time (Matthews et al., 2008; Purman, 2008), usually measured in tonnes (t) of CO_2 or, for other greenhouse gases, as CO_2e representing their atmospheric warming potential using a common denominator. Thus, it differs from the ecological footprint in that it does not characterise activities in the explicit context of the carrying capacity of Earth, but rather in the implicit context of the carrying capacity of Earth's atmosphere.

2.4.2(a) The Scopes of Carbon Footprints

There is considerable variability in the approaches taken to carbon footprinting (Kenny & Gray, 2009; Pandey, Argrawal, & Pandey, 2011). Regardless of how energy consumption and emissions are inventoried, though, carbon footprints are typically described in terms of three 'scopes'.

Scope 1 Emissions: The emissions associated with the petrol and diesel consumed to operate an organisation's vehicle fleet would be an obvious component of that organisation's carbon footprint. Equally apparent would be the emissions associated with burning natural gas, fuel oil, kerosene or other fuels in furnaces or, perhaps, in on-site generators that produce electricity. Accounting for these types of *direct* energy consumption and their resultant emissions is classified as a Scope 1 carbon footprint (Australian Government Department of Climate Change, 2009a; Matthews, Hendrickson, & Weber, 2008; Purman, 2008).

Scope 2 Emissions: Less obvious, but equally logical, is to include the emissions associated with purchased energy in an organisation's carbon footprint. The most common example is emissions associated with electricity generation. Although using electricity to power equipment in a factory or office doesn't produce emissions directly from that factory or office, the process of generating that electricity—typically in coal-fired power plants—does produce emissions. Organisations should account for the emissions that result from generating the electricity they consume. Although somewhat rare in the modern world, the same would be true for organisations that utilise municipally-generated piped-in steam. A more common—and often overlooked—example is the emissions associated with employees' work-related commercial air (or rail) travel. Accounting for these types of *indirect* purchased energy consumption and their resultant emissions is classified as a Scope 2 carbon footprint (Australian Government Department of Climate Change, 2009a; Matthews, Hendrickson & Weber, 2008; Purman, 2008).

Scope 3 Emissions: Scope 3 carbon footprints account for the 'upstream' emissions that arise from producing the supplies and equipment used by an organisation, as well as the 'downstream' emissions associated with disposing of the waste generated by that organisation and its products or services (Australian Government Department of Climate Change, 2009a; Lenzen, Murray, Sack, & Wiedmann, 2007; Matthews, Hendrickson, & Weber, 2008; Purman, 2008; Ross & Evans, 2002). In terms of products and processes that are only one or two steps away from an organisation's final product or service, the concept isn't outlandish: it is reasonable that a freight company would account for the emissions associated with manufacturing the tyres used on its trucks, or that a hospital would account for the emissions associated with commercial laundering of its linens. A true Scope 3 analysis, however, goes further. For example, a hospital would also account for a pro-rata portion of the emissions associated with manufacturing the tires used on the delivery vans of the commercial laundry that providers its linen service, and so forth.

Complete Life Cycle Emissions: Although the phrase 'Scope 3 carbon footprint' is sometimes used synonymously with '*complete life cycle*' carbon footprint, a ‘complete life cycle’ carbon footprint is actually the sum of Scope 1, Scope 2 and Scope 3 emissions. The concept behind Scope 3 carbon footprints and life cycle analysis is important from two perspectives. First, the fossil energy consumption and related emissions represented in Scope 1 and Scope 2 carbon footprints do not adequately characterise the environmental impact of most products and services (Huijbregts et al., 2006; Matthews, Hendrickson, & Weber, 2008; Purman, 2008). Second, if upstream and downstream impacts are not considered in an organisation’s carbon footprint, emission reduction strategies could lower Scope 1 and Scope 2 emissions while total emissions from upstream or downstream processes actually rise. The direct emissions resulting from the organisation’s activities would decrease, but total emissions into the atmosphere—the ultimate target of greenhouse gas mitigation efforts—would increase. One striking example of how reductions in Scope 1 emissions can be misleading is bio-fuels. While the exact impacts vary by both the source material (for example, corn vs. switch-grass) and production processes, in many cases the reduction in direct carbon emissions that results from using bio-fuels instead of fossil fuels is more than offset by the emissions associated with cultivating the plant stock and refining it into fuel, as well as by the resultant land use changes that can affect both ecosystems and food chains (Coronada, de Carvalho, & Sliveira, 2009; Gnansounou, Dauriat, Villegas, & Panichelli, 2009; Huo, Wang, Bloyd, & Putsche, 2009; Lange, 2011; Lapola et al., 2010; Reijnders, 2011; Searchinger et al., 2008; Solomon, 2010).

The International Organisation for Standardisation (ISO) addresses life cycle analyses in two standards: ISO 14040 and ISO 14044, identifying seven principles of life cycle analysis (Table 2.2) (Finkbeiner, Inaba, Tan, Christiansen, & Kluppel, 2006). One key point is that the complexity of and varying approaches to life cycle analysis make comparisons between the carbon footprints of individual organisations perilous.

Carbon footprints, including those based on life cycle analysis, are better used to systematically and iteratively track emissions from a single organisation (or sector) over time, using a consistent methodology to minimise the risk of differential bias in the sequential measurements (Purman, 2008).

Table 2.2: Principles of 'life cycle assessment' (Adapted from Finkbeiner et al., 2006).

Life cycle assessment considers the entire life cycle of a product.
Life cycle assessment addresses the environmental impacts of a product system.
Life cycle assessment is a relative approach structured around a functional unit.
Life cycle assessment is an iterative technique.
Transparency is an important guiding principle in executing life cycle assessments.
Life cycle assessment considers the natural environment, human health and resources.
Decisions within a life cycle assessment are preferably based on natural science.

Accounting for Scope 3 energy consumption and emissions is not simple. There are different approaches to allocating shares of responsibility along the supply chain; for example, dividing emissions equally between each successive supplier and consumer, or pro-rating emissions by the value added at each upstream transaction (Lenzen, Murray, Sack, & Wiedmann, 2007). There is also some discussion about how far up (or down) the supply chain to track emissions (Huang, Weber, & Matthews, 2009). None-the-less, the principle of complete life cycle analysis—of accepting at least some responsibility for upstream and downstream emissions—is well established in ecological footprinting and is becoming the preferred approach for carbon footprints as well (Huijbregts et al., 2006; Lenzen et al., 2007; Lenzen & Murray, 2010; Matthews, Hendrickson, & Weber, 2008; Purman, 2008; Ross & Evans, 2002). At the same time, practicalities might limit the ability of individual organisations to undertake (or commission) extensive complete life cycle evaluations of their products and services (Australian Government Department of Climate Change, 2009a; Matthews et al., 2008) and in such cases Scope

1 and Scope 2 emissions inventories (with an acknowledgement that Scope 3 emissions are not accounted for) can still be useful.

2.4.3 Conducting Energy Consumption and Emissions Inventories

2.4.3(a) Approaches

There are three general approaches to conducting emissions inventories:

Bottom-up approaches identify each step or process involved in producing a product or delivering a service—and preferably all of the upstream and downstream components of each step or process—and explicitly measure the associated energy consumption and greenhouse gas emissions. In a bottom-up approach, it is reasonably easy to identify the emissions associated with, for example, electricity used to power a factory or fuel consumed by delivery vans. Thus, the bottom-up approach is widely used in determining Scope 1 and Scope 2 carbon footprints. Conversely, a bottom-up approach to identifying upstream emissions requires access to significant amounts of data about the operations of potentially hundreds or thousands of firms and organisations in the supply chain, making a bottom-up approach to a complete life cycle assessment a truly daunting, if not impossible, task (Hamilton, Kellet, & Yuan, 2008).

Top-down approaches typically identify the total emissions associated with economic activities at some aggregate scale—an economic sector, a region, a nation, etc.—and then allocates a share of those emissions to an individual firm or organisation through some pro-rating technique such as by market share or proportion of gross domestic product. Top-down approaches inherently include complete life cycle emissions, but they assume that emission intensity—emissions per unit of product or service delivered or per unit of economic activity—is constant across all firms or organisations within the parent sector, region or nation (Hamilton, Kellet, & Yuan, 2008; Turner, Lenzen, Wiedmann, & Barrett, 2007).

Hybrid life cycle analyses recognise the relative strengths and shortcomings of bottom-up and top-down methods of emissions inventories, and attempt to provide a more complete accounting of an organisation's emissions by combining aspects of both. For those aspects of the organisation's activities that lend themselves to explicit measurement of their energy burden and emissions, a bottom-up approach is employed. For those aspects of the organisation's activities for which explicit energy consumption and emissions data cannot practicably be obtained, a top-down approach is used (Hamilton, Kellet, & Yuan, 2008; Stromman, Peters, & Hertwich, 2009; Suh, 2004). One important caveat in hybrid life cycle analyses, however, is to ensure that emissions are not double-counted; that is, to ensure that any emissions explicitly measured in the bottom-down component are not included in (or are deducted from) aggregate emissions incorporated into the top-down portion of the analysis (Stromman et al., 2009; Suh, 2004).

2.4.3(b) Input-Output Analysis

A well-established methodological approach to identifying and allocating upstream and downstream emissions when conducting top-down and hybrid life cycle analyses is the use of input-output analysis. Input-output analysis was developed by the economist Wassily Leontief (who won the Nobel Prize in economics for that work) as a way to use matrix algebra to measure and model transactions between all of the sectors of an economy, and thus the upstream and downstream economic flows that result from the transactions of any given sector (or firm within a sector). In1970, he described how pollution, as a by-product of economic activity, could be incorporated into input-output models and showed that such models could then subsequently be used to evaluate how changes in one economic activity might affect cumulative pollution from all of the upstream and downstream points in the supply chain (Leontief, 1970). Since then, input-output analysis has been widely incorporated into analyses of energy consumption and environmental impacts (de Haan & Keuning, 1996; Herendeen, 1978; Turner, Lenzen, Wiedmann, & Barrett, 2007; Wiedmann, Minx, Barrett, & Wackernagel, 2006), including for example the environmental impacts of: economic sectors within national economies (Cadarso, Lopez, Gomez, & Tobarra, 2010; Liu, Langer, Hogh-Jensen, & Egelyng, 2010; Rotz, Montes, & Chianese, 2010; Schmitz, Kaminski, Scalet, & Soria, 2011; Tan, Wijaya, & Khoo, 2010; Tarancon, del Rio, & Callejas, 2011); international trade (Hubacek & Giljum, 2003; Lenzen, Pade, & Munksgaard, 2004; Rueda-Cantuche & Amores, 2010; Su & Ang, 2010; Su, Huang, Ang, & Zhou, 2010; Wiedmann, Lenzen, Turner, & Barrett, 2007); waste management strategies (Bailey, Amyotte, & Khan, 2010; Dietzenbacher, 2005; Rigamonti, Grosso, & Giugliano, 2010); global cities (Kennedy et al., 2010) and individual firms and organisations (Baboulet & Lenzen, 2010; Scipioni, Mastrobuono, Mazzi, & Manzardo, 2010).

Through input-output analysis, an organisation is held accountable for a portion of the emissions resulting from mining the ore that was smelted into steel that was formed into beams that were used in the construction of the factory that built the truck that delivered the petrol to the newly opened fuel station 10 kilometres down the road where that organisation refuels its vehicles. Input-output analysis is truly a complete life cycle accounting mechanism.

2.5 Summary

The consumption of fossil fuels, rising atmospheric CO2 levels, and increasing global surface temperatures are all inter-related. Fossil energy is not limitless, and it is likely the world has already surpassed the point of peak oil production. Fossil energy is also becoming increasingly expensive. For these reasons, managing energy consumption and greenhouse gas emissions is important for all firms and organizations, including health services.

The ‘carbon footprint’ is one measure of the energy consumption and greenhouse gas emissions associated with any activity. Carbon footprints are typically described in three scopes. Scope 1 emissions arise from direct energy consumption; Scope 2 emissions arise from purchased energy consumption; and Scope 3 emissions arise from energy consumption in the upstream and downstream processes of the production chain.

It is within this framework that this thesis explores the energy and environmental burden of Australian ambulance services. The next chapter begins that effort by surveying the reported energy consumption and environmental impacts of health services, including ambulance services.

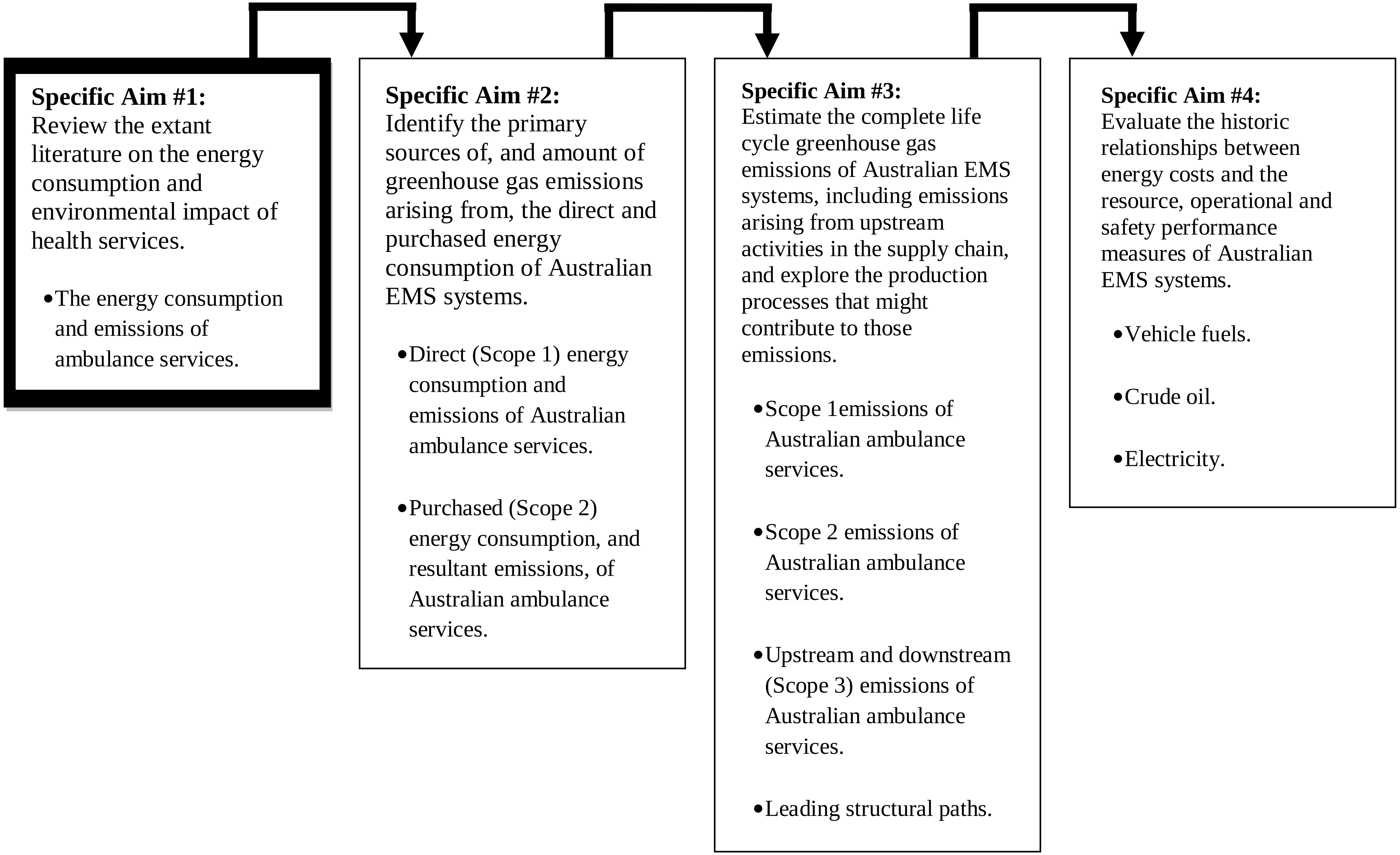
Chapter 3: Literature Review

The previous chapter summarised the theoretical and empirical foundations for climate change, energy scarcity, and rising energy costs, as well as the methodological approaches to greenhouse gas and energy accounting. This chapter describes the first specific aim of this thesis: The initial literature search exploring the energy consumption and greenhouse gas emissions of health services (Figure 3.1).

The formal literature search for this chapter was last updated 04 March 2011. It was updated approximately monthly there-after, and a few additional relevant articles were identified and are referenced in the discussion section of this chapter, as well as in later chapters of the thesis.

This chapter has been adapted into a manuscript: Brown, L.H., Canyon, D.V., Buettner, P.G. (In Press). The energy consumption and environmental impact of health services: A review. *American Journal of Public Health*. Accepted 04 March 2012. Documentation of acceptance is included in Appendix 2.

A detailed analysis of the articles included in this literature search is included as Appendix 6.



Specific Aim #1:
Review the extant literature on the energy consumption and environmental impact of health services.

- The energy consumption and emissions of ambulance services.

Specific Aim #2:
Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

- Direct (Scope 1) energy consumption and emissions of Australian ambulance services.
- Purchased (Scope 2) energy consumption, and resultant emissions, of Australian ambulance services.

Specific Aim #3:
Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute to those emissions.

- Scope 1emissions of Australian ambulance services.
- Scope 2 emissions of Australian ambulance services.
- Upstream and downstream (Scope 3) emissions of Australian ambulance services.
- Leading structural paths.

Specific Aim #4:
Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

- Vehicle fuels.
- Crude oil.
- Electricity.

Figure 3.1: Progress through the thesis: Specific Aim #1.

3.1 Abstract

Understanding the energy consumption and environmental impact of health services is important for both minimising their impact and guiding their adaptation to a low-carbon economy. This review summarises the English language literature on the energy burden and environmental impact of health services. All years of the PubMed, CINAHL and *ScienceDirect* databases were searched to identify publications reporting energy consumption, greenhouse gas emissions, and/or the environmental impact of health-related activities. Data were extracted and tabulated to enable cross-comparisons among different activities and services; where possible, per-patient or per-event emissions were calculated. Thirty-two relevant publications were identified. On a per-patient or per-event basis, energy consumption and greenhouse gas emissions are quite modest; on an aggregate basis, however, they are substantial. In England and the U.S., health-related emissions account for 3% and 8% of total national emissions, respectively. While reducing health-related energy consumption and greenhouse gas emissions alone will not solve all of the problems around energy scarcity and climate change, it can make a meaningful contribution.

3.2 Search Strategies

3.2.1 Searching the Medical Literature

In order to identify published articles reporting or evaluating the energy consumption of and/or greenhouse gas emissions arising from health services, the National Library of Medicine (PubMed) database was searched using the Entrez search engine. The search strategy (Table 3.1) included relevant search terms identified using the search engine's medical subject heading (MeSH) thesaurus; it was intended to be as sensitive, rather than as specific, as possible. The search was first executed 09

November 2009 and updated approximately monthly thereafter, with the final update executed on 04 March 2011.

Table 3.1: The PubMed and CINAHL search strategy.

1. exp greenhouse effect/
2. exp energy-generating resources/
3. 1 *and* 2
4. greenhouse gases.mp.
5. greenhouse gasses.mp.
6. carbon footprint.mp.
7. carbon emissions.mp.
8. 3 *or* 4 *or* 5 *or* 6 *or* 7
9. limit to English

mp – multipurpose

The citations generated by the search were reviewed to determine their relevance, and subsequently the abstracts of all the potentially relevant papers were reviewed to further narrow the search results. A fairly low threshold for inclusion was maintained in the belief even marginally relevant studies could provide useful insights.

The Cumulative Index to Nursing and Allied Health Literature (CINAHL) was also searched using the EBSCOhost search engine (EBSCO Publishing, Ipswich, MA) and the same search strategy. The CINAHL search was last executed 19 February 2011. Again, the list of titles generated by this search was reviewed to first exclude those articles that had already been identified by the PubMED search and then to identify all of the additional potentially relevant articles. The resulting set of articles was sufficiently small that it was possible to move directly to full manuscript review.

3.2.2 Searching the Energy, Environmental and Economics Literature

It was also possible that articles relevant to the study question could be published in non-medical journals. Thus, to supplement the searches of the health-related literature, all years of the *ScienceDirect* database were searched using a more focused strategy, shown in Table 3.2. As with the primary search of the medical literature, relevant papers were identified by first considering the titles, then the abstracts, and ultimately the full texts of the identified citations. This search was first executed in April 2010, and was also last updated for this chapter on 04 March 2011.

Table 3.2: The *ScienceDirect* search strategy.

1. TITLE-ABSTR-KEY (ambulance *or* hospital)
2. ALL (greenhouse gas* *or* carbon footprint *or* emissions)
3. 1 *and* 2

* – truncated; ABSTR – abstract

After further exploring the *ScienceDirect* database using a variety of search terms, exploring other databases and search engines available through the James Cook University library, and discussing the issue with a colleague in the Economics department who studies water-related environmental issues, the decision was made to bolster this effort using a cursory search of the ‘Economics, Econometrics and Finance’ subject subset of the *ScienceDirect* database using the search phrase, ‘carbon footprint’, followed by manually searching the tables of contents of journals that had published papers deemed relevant.

A list of 21 journals with the greatest potential to publish relevant papers was created from the reference lists of example theses on related topics, the references of the most relevant papers identified in the first execution of the search of the medical literature and the *ScienceDirect* database, and from papers with related themes that had been suggested by colleagues. Nine of these journals are indexed in PubMed and thus relevant articles could be captured by the primary search strategy, but for the remaining 12 journals (Table 3.3) the *ScienceDirect* database was used to access and manually review their tables of contents.

Table 3.3: Energy and environmental journals subjected to table of contents search.

Ecological Economics
Energy
Energy Conversion & Management
Energy Economics
Energy Policy
Environmental Impact Assessment Review
Global Environmental Change
Journal of Cleaner Production
Journal of Environmental Economics and Management
Land Use Policy
Renewable Energy
Transportation Research Part D

This search was first executed in April 2010, including all issues published since the beginning of the previous year; the search was updated in August 2010, and then approximately each month thereafter until March 2011. For this search process it was more efficient to review the titles and abstracts simultaneously, and then download the full text of any potentially relevant articles. As with the primary search of the medical literature, a low threshold was maintained for relevance and inclusion.

3.2.3 Identifying Additional Papers

Additional relevant papers were identified from the references of the articles identified by these two search processes, from additional personal reading, and through referrals of related papers from colleagues.

3.2.4 Categorisation and Classification of Articles

Even within the results of the PubMed and CINAHL searches, the vast majority of the identified articles were not specifically relevant to energy or emissions inventories in health or medical settings. This was more true for the results of the *ScienceDirect* and table of contents searches, as well as for the additional articles identified by reviewing cited references. To organise these papers into common themes, they were sorted into the categories shown in Table 3.4. The primary emphasis was on identifying articles that reported efforts to measure, characterise or mitigate energy consumption and emissions in health or medically related settings; the remaining categories included papers reporting background information on greenhouse gas emissions and climate change, methodological approaches to inventorying and modelling energy consumption and greenhouse gas emissions, and examples of energy- and emissions-related studies from other disciplines that might serve as useful models.

The subset of articles addressing energy consumption and emissions in health and medical settings was further classified in a method similar to that used in previous public health related literature surveys (Sanson-Fisher, Campbell, Perkins, Blunden, & Davis, 2006; Sanson-Fisher, Campbell, Htun, Bailey, & Millar, 2008) as being: original research; brief reports and research letters; advocacy articles and letters (including those in trade journals); government agency reports; editorials and commentaries; and news items.

3.2.5 Extraction of Data

For those papers reporting energy consumption and/or emissions data in health or medical settings—including original research articles, brief reports and research letters, and government agency reports—data were extracted and tabulated to the extent possible in order to form a rough understanding of the energy and environmental burden of health services, and to enable some crude cross-comparisons among different activities and services. For the emissions data, where possible, per-patient or per-event emissions were calculated by dividing total reported emissions by the number of patients or events represented in the data.

3.3 Results

3.3.1 Overall Search Results

As at 04 March 2011 the PubMed search had identified 938 titles for review, the CINAHL search had identified 66 titles, and the *ScienceDirect* search had identified 40 titles. From these, 413 were selected for abstract review with 223 retained for evaluation of the full manuscript; nine of these, however, could not be obtained. The cursory search of the *ScienceDirect* 'Economics, Econometrics and Finance' subject subset, the table of contents search (which included review of the contents of 251 journal issues), and searching the reference lists of the identified papers and related theses identified more than 600 additional citations (although many were duplicates); from these, 283 articles were obtained for full review. In total, over the course of 16 months nearly 500 potentially relevant publications were read in their entirety. The results of the search process are shown in Figure 3.2.

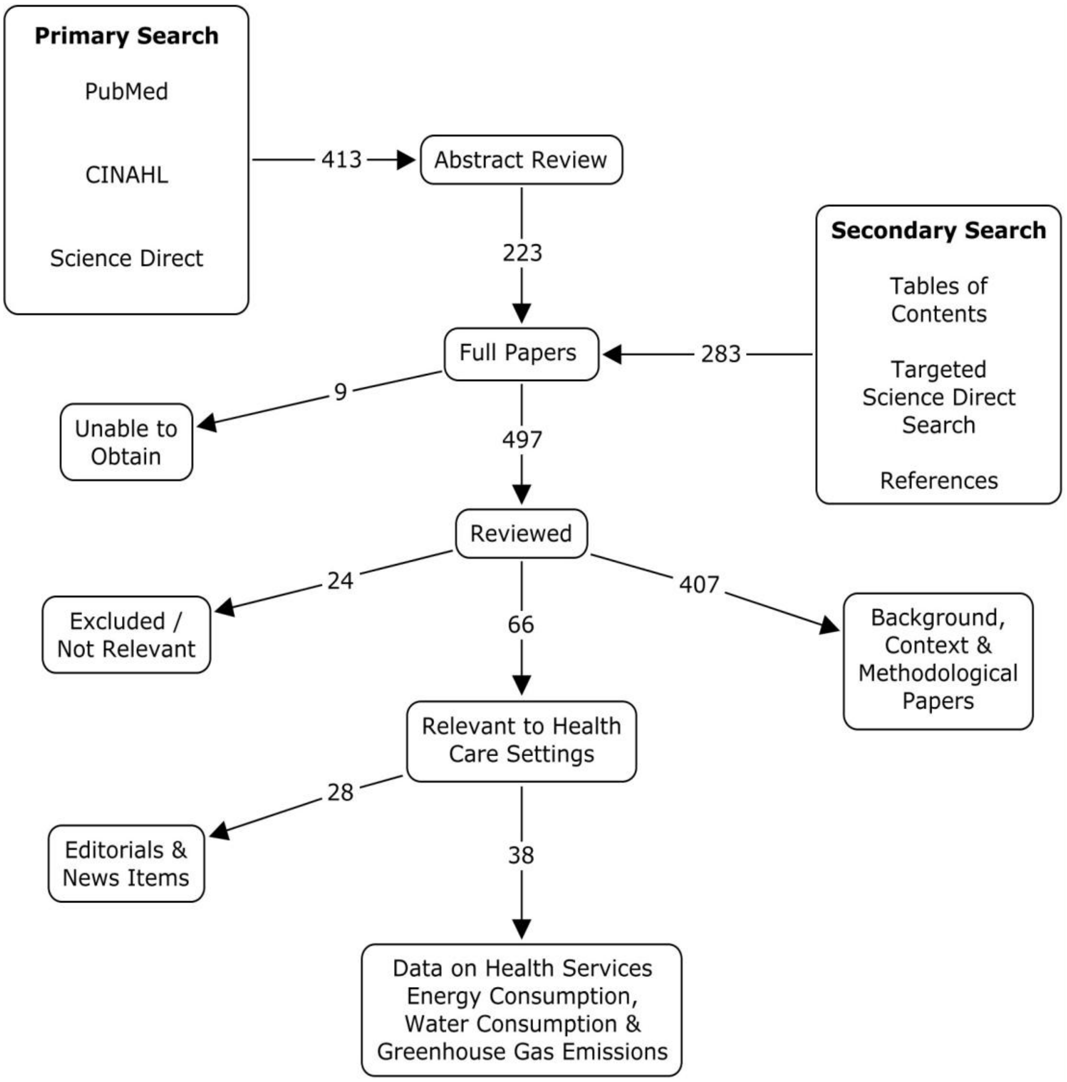


Figure 3.2: Results of the search process.

The vast majority of the papers addressed background or context related to greenhouse gas emissions and climate change, described methodological approaches to energy and emissions accounting, or reported energy- or emissions-related studies in other industries that could potentially be replicated in the EMS setting (Table 3.4). Many of these 497 papers formed the basis for Chapter 2 of this thesis.

Table 3.4: Categorisation of articles identified by the literature search (N=497).

Categorisation		Number of Articles*
Energy Consumption/Emissions Related to Health & Medicine		66
(see 'classification' table for further sub-categorisation)		
Background Information, including…		314
Climate Change	(25)	
Health Effects of Emissions/Climate	(41)	
Economic-Environmental Linkages	(32)	
Peak Oil	(13)	
Energy Costs	(21)	
Cities & Urban Issues	(9)	
Buildings	(19)	
Mitigation Efforts and Policies	(71)	
Backfire and Rebound	(8)	
Alternative Energy (e.g., wind, solar)	(20)	
General Vehicle Emissions	(13)	
Electric Vehicles	(13)	
Bio-fuels	(26)	
Aviation	(4)	
Methodological Papers, including…		111
Carbon Footprint/Emissions Inventories	(11)	
Ecological Footprint	(16)	
Life Cycle Analysis/Input-Output Analysis	(28)	
Decomposition Methods and Examples	(24)	
Footprints/Accounts; Nations & States	(20)	
Australian Specific Accounts & Footprints	(12)	
Studies from other Industries, including…		12
Services	(3)	
Tourism & Hotels	(9)	
Full Paper Reviewed and Rejected/Not Relevant		24

* some papers are represented in more than one category

3.3.2 Energy Consumption and Emissions in Health Services

Only 66 unique publications addressed environmental issues related to health-related activities. Forty-two percent of the publications were editorials or commentaries (n=12), non-research articles (n=2), and news items (n=14) that did not include any data; fifty-eight percent (n=38) of the publications provided data in some form, but only 22 of these were genuine peer-reviewed articles reporting original research findings. The articles that provided actual data are further classified in Table 3.5, and detailed in Appendix 6.

Table 3.5: Classification of the articles reporting data on energy consumption or emissions associated with health or medicine.

Topic	Original Research	Brief Reports & Research Letters	Advocacy Articles & Letters	Govt. Reports	Duplicate Data
Emergency Medical Services	2	-	1	-	-
Health Sector Emissions	-	1	-	2	1
Surgery	3	2	-	-	-
Dialysis	4	-	-	-	-
Surgical Scrubbing	1	1	-	-	-
Hospitals	12	-	1	-	-
Clinical Trials	-	1	-	-	-
Telemedicine	-	-	2	-	-
Professional Meetings	-	-	3	-	-
Subspecialty Training	-	-	1	-	-
Total	22	5	8	2	1

Energy consumption and environmental issues in hospitals were the most common topics of study, being the foci of more than half (n=12) of the peer-reviewed papers, but six of these papers were technical analyses of energy generation or waste management systems. Thus, 32 papers explicitly reported measured or modelled energy consumption, greenhouse gas emissions or water consumption in health settings; these form the core of this review. Twenty-two of these papers reported original data collection and analysis, either through empirical study or modelling; the remaining ten papers were advocacy or non-research articles reporting secondary or anecdotal data.

3.3.2(a) Emergency Medical Services

The two peer-reviewed research papers addressing energy consumption of and emissions from EMS systems identified by the search were papers related to, but not included as chapters within, this thesis. Having demonstrated the ability of EMS systems to provide the necessary data in a ‘proof of concept’ study (Blanchard & Brown, 2009), a colleague and I had undertaken a study to characterise the carbon emissions from a broad sample of North American EMS agencies (Blanchard & Brown, 2011) (Appendix 5). Fifteen diverse North American EMS systems with over 550,000 combined annual responses and serving a population of 6.3 million reported their direct and purchased (Scope 1 and Scope 2) energy consumption for one year. Participating agencies included government ‘third service’ (n=4), public utility model (n=1), private contractor (n=6) and rural rescue squad (n=4) systems. Their annual call volumes ranged from 800 to 114,280 (median 20,093; inter-quartile range (IQR) 1,100 – 55,217).

Total CO_2e emissions were calculated using Environmental Protection Agency, Energy Information Administration (EIA) and locality specific emission conversion factors. Per-response and population-based emissions were also calculated. Emissions totalled 21,289 t CO_2e; 75% of emissions were from diesel or gasoline consumption. For systems providing complete Scope 1 and Scope 2 data for ground ambulance operations, emissions averaged 45.5 kg CO_2e per response; median emissions per response were 36.6 (IQR 29.5 – 48.3) kg of CO_2e and median emissions per service-area resident were 3.5 (IQR 2.1 – 5.1) kg of CO_2e . Two systems reported aviation fuel consumption for air medical services, with emissions of 1.1 t CO_2e per flight, or 0.3 kg of CO_2e per service-area resident. Using population and ambulance response data for the U.S., this study estimated that annual EMS emissions in that nation total between 660,000 and 1.6 million t CO_2e.

In one trade journal article, Hawkins (2008) described the use of a gasoline-electric hybrid sports utility vehicle as an EMS quick response vehicle (QRV), asserting that such a vehicle can perform as well as traditional heavy duty QRVs while reducing both fuel costs and emissions.

3.3.2 (b) Emissions from the Health Sector

The most aggressive attempt to identify and reduce greenhouse gas emissions associated with health and medical services has been undertaken by England's National Health Service's (NHS) 'Sustainable Development Unit (SDU)' in collaboration with the Stockholm Environment Institute. The SDU was established to monitor consumption and encourage energy efficient practices in NHS England; its director, Dr. David Pencheon, has reportedly said that energy use and climate change are essential issues for the NHS (Creagh, 2008).

Supplementing input-output analysis based on NHS expenditures with more detailed data on building energy consumption and travel estimates from a National Travel Survey, the total life cycle carbon footprint of NHS England for calendar year 2004 was estimated at 21.3 million tonnes (Mt) of CO_2e, or approximately 3.2% of all emissions in England (Sustainable Development Commission-Stockholm Environment Institute, 2008). Eighty-seven percent of those emissions (18.6 Mt) were CO_2 emissions, with the remainder (2.7 Mt) being CO_2e emissions of other greenhouse gases. Upstream and downstream emissions associated with procurement of supplies and equipment and disposal of wastes accounted for approximately 60% of all emissions (Table 3.6); acquisition of pharmaceuticals was the greatest single contributor to the carbon footprint of NHS England, accounting for 21% of total emissions. In a 2007 update, CO_2e emissions from NHS England activities were 21 Mt (Sustainable Development Unit, 2010), with a projected increase—in the absence of significant reductions in energy consumption—up to 23 Mt by the year 2020 (Brockway, 2010). The British Dental Association has urged its members to do their part to help the NHS reduce its environmental impact (Anonymous, 2008), and a similar call has been issued to NHS nurses (Blakemore, 2009).

Table 3.6: Carbon footprint of NHS England, 2004 (adapted from SDC-SEI, 2008).

	Emissions	
Activity	Mt CO_2e	% of Total
Procurement & Waste Disposal	13.24	62%
Building Energy Use	4.59	22%
Patient, Visitor and Staff Travel	3.45	16%
Total	21.28	100%

CO_2 – carbon dioxide; CO_2e – carbon dioxide equivalents; Mt – million tonnes; SDC-SEI – Sustainable Development Commission-Stockholm Environment Institute

Using published data on health expenditures for the year 2007 and the Environmental Input-Output Life-Cycle Assessment (EIO-LCA) model developed and supported by the Carnegie Mellon University Green Design Institute (2010a), Chung & Meltzer (2009) calculated aggregate complete life cycle emissions for the U.S. health care sector. They calculated an annual carbon footprint for medical care and health services in that nation of 545.5 Mt of CO_2e emissions, with 46% being direct emissions from energy consumption and 54% being indirect emissions associated with upstream and downstream processes including procurements. The total estimated emissions from the U.S. healthcare sector represent approximately 8% of total U.S. greenhouse gas emissions.

3.3.2(c) Surgical Procedures

Gastric reflux can be managed with medication or with surgery. Citing two multicentre trials that concluded surgical management was at least as good as, if not better than, medical management, Gatenby (2011) argued that patients and physicians might consider the respective environmental impacts of the two approaches when deciding which to pursue. Using the reported emission intensity per pound of expenditure for the U.K. NHS, he estimated the carbon emissions associated with the management of 164 patients receiving medical treatment and 154 patients undergoing surgery. The initial cost of surgery was nearly seven times greater than that of medical management, and thus estimated initial emissions from surgery were also nearly seven times greater than from medical management: 1007.5 kg CO_2e vs. 147.4 kg CO_2e. However, estimated emissions from continuing treatment were much lower for patients undergoing surgery: 30 kg CO_2e per year compared to 100 kg CO_2e per year. He calculated that the surgical approach would become "carbon-efficient in the 9th post-operative year", (Gatenby, 2011, p. 73) noting that on average these patients have life expectancies of approximately 40 more years.

A recent study comparing the environmental impact of two approaches to cataract surgery (Somner, Scott, Morris, Gaskell, & Shepherd, 2009) compared the paper and plastic waste, as well as the electricity consumed by specialised equipment, for the 'phacoemulsification' and 'modified phacosection' techniques. The study also examined the number of patient visits required for the procedure, and estimated the emissions associated with patient travel. The authors found the modified phacosection technique produced 280 grams (g) less plastic waste, 8 g less paper waste, and used 0.168 kilowatt hours (kWh) less electricity than the phacoemulsification technique. They also found that completing the entire procedure in a single visit instead of a five-visit strategy including referral, pre-operative assessment, and post-operative appointments would reduce travel-related CO_2 emissions by 29.8 kg per procedure. When extrapolating their findings to the 10.2 million cataract operations performed around the world each year the authors concluded, “The global impact of ophthalmology services is much less than 1 coal-fired power station per annum; nevertheless, ophthalmologists can reduce the ophthalmology carbon footprint and the impact of their practice without jeopardizing patient care” (Somner et al., 2009, p. 203).

Laparoscopic surgeons insufflate patients’ abdomens with compressed CO_2 to provide a better view and space to manipulate surgical instruments. Gilliam, Davidson, & Guest (2008) evaluated the amount of CO_2 used in laparoscopic surgeries at a single district general hospital. They found that the number of surgeries had increased four-fold over a ten-year period, with median procedure times of 1.01 hours. They estimated that a C-sized cylinder of compressed CO_2 should last approximately four hours (and thus, four procedures) and that each cylinder releases only 0.0009 t (~1 kg) of CO_2 into the atmosphere. They concluded that “… laparoscopic surgery uses only tiny amounts of CO_2, [and] its impact on global warming is minimal” (Gilliam et al., 2008, p. 573).

Noting that inhaled anaesthetics used in surgery are exhaled by the patients, collected by the anaesthesia machines, and then vented as waste gas into the outside air, Ryan & Nielsen (2010) determined the 20-year GWP (GWP_{20}) of three common anaesthetic gases and then applied them to clinical scenarios to estimate their relative environmental impacts. As shown in the Table 3.7, sevoflurane had the lowest GWP_{20} (349), followed by isoflurane (1401) and desflurane (3714).

Table 3.7: Global warming impact of common anaesthetic gases (adapted from Ryan & Nielsen, 2010).

Anaesthetic	GWP_{20}	FGF rate	20-year CO_2e (g/hr)
2% sevoflurane	349	2 L/min	6,980
1.2% isoflurane	1401	2 L/min	15,551
		1 L/min	7,762
		0.5 L/min	3,881
6% desflurane	3714	2 L/min	187,186
		1 L/min	93,593
		0.5 L/min	46,796

CO_2e – carbon dioxide equivalents; FGF – fresh gas flow; g – grams; GWP_{20} – 20 year global warming potential; hr – hour

As would be expected, at a constant fresh gas flow (FGF) rate of 2 L/min sevoflurane had the lowest 20-year CO_2e emissions (6.9 kg/hr), followed by isoflurane (15.6 kg/hr) and desflurane (187.2 kg/hr). When taking into account the lower FGF rates at which isoflurane and desflurane might be administered because of their greater potency, the emissions from isoflurane were somewhat similar to those of sevoflurane (3.9 – 7.8 kg/hr), while emissions from desflurane remained significantly higher (46.8 kg/hr). The authors concluded, “Desflurane has a significantly larger global warming impact compared with sevoflurane or isoflurane, particularly at higher FGF rates or longer delivery times” and pointed out that anaesthesiologists can adopt strategies “…to minimize their environmental impact when delivering inhaled anesthetics” (Ryan & Nielson, 2010, pp. 96-97).

Importantly, both of these studies were limited to the direct emissions associated with these medical gases; neither accounted for the complete life cycle emissions associated with producing, bottling and distributing these gases, which could be substantial. Although medical gases are not specifically identified, the Carnegie-Melon based EIO-LCA life cycle assessment tool estimates 4.6 t of CO_2e are emitted for every $1,000 in purchases from U.S. industrial gas manufacturers (Carnegie Mellon University Green Design Institute, 2010b).

One laboratory study (Bayazit & Sparrow, 2010) has explored the energy consumption of different perioperative warming devices. Two convective-air warming devices and two direct-contact conduction warming devices were evaluated using thermocouples and heat-flux sensors applied to a constant-temperature heat sink serving as a surrogate patient. Energy efficiency was measured as the ratio of the rate at which energy was absorbed by the heat sink to the rate at which energy was consumed by the warming device. The authors found that neither category of device was more efficient than the other; instead they concluded, "… the appropriate use of insulation and the suppression of pathways of extraneous heat loss have to be considered in the design of patient warming devices. It is these factors that created significant differences in the energy utilisation efficiencies of investigated devices…" (Bayazit & Sparrow, 2010, p. 1214).

3.3.2(d) Water Consumption

Dialysis is a lifesaving treatment for many people with kidney disease, who often require multiple treatments each week either in a clinic setting or at home. Dialysis is, however, a water-intense therapy consuming between 120 to 800 litres (L) of fresh water for each treatment, depending on the type (clinic vs. home) and duration of the therapy session (Agar, 2010; Agar, Simmonds, Knight, & Somerville, 2009; Tarrass, Benjelloun, & Benjelloun, 2008). Much of that water is discarded in the reverse osmosis process which creates the dialysis fluid, and it is known as ‘reject water’ (RW). While officially a medical waste product, RW has been shown to be essentially bacteria-free, with pH, turbidity and electrolyte characteristics not unlike those of municipal and industrial water supplies (Agar, 2010; Agar et al., 2009; Tarras et al., 2008). As such, recycling of RW for use as gray water—for example, irrigating lawns or flushing toilets—has been advocated and even trialled in some settings (Agar, 2010). The cost of recycling RW is estimated to be less than that of generating fresh water through reverse osmosis of sea water (Tarrass et al., 2008). This practice, however, is not widespread. For example, only two of 58 renal units in England, Scotland and Wales that participated in a survey on ‘sustainability in kidney care’ reported having RW recycling facilities; indeed, nearly two-thirds of the participating centres didn’t even have water-saving taps for their sinks (Connor & Mortimer, 2010).

The ‘sustainability in kidney care’ survey also provided additional insights into the energy conservation efforts of U.K. dialysis centres. Only 30% of the responding centres used low-energy light bulbs in all or most of their light fixtures; only two centres used solar energy to supplement their electricity consumption and none used wind turbines; in 61% of the facilities the staff could not adjust the heating or air conditioning (which arguably could be either an energy saver or an energy waster). More positively, more than 80% of the responding centres actively encouraged staff to bicycle to work and provided cycle parking and shower facilities to support that, and 25% recaptured heat from the dialysis effluent to offset some of their energy burden (Connor & Mortimer, 2010).

Somner et al. (2008) evaluated two types of water taps for surgical scrub sinks to determine whether “environmentally friendly scrubbing behaviour [would lead] to less energy and water expenditure per scrub” (Somner et al., 2008, p 213). They observed scrubbing at two Scottish hospitals, one where the tap was turned on using the elbow and one where the tap was turned on with the leg, recording the length of time for which the tap was running using a stopwatch. Six doctors and eight nurses scrubbed a total of 25 times. Where the tap was activated by the elbow, the tap was on for a mean of 2 minutes and 23 seconds per scrub; where the tap was activated by the leg, the tap was on for a mean of 1 minute and 7 seconds. This translated to a difference of 5.7 L of water per scrub, and the authors estimated that changing all U.K. surgical sinks from elbow-activated to leg-activated taps would save approximately 11,000 gigajoules (GJ) (or 3,000,000 kWh) annually in energy required to heat the water. They concluded, "… if we are all to play a part in reducing our impact on the environment, simple interventions like this can combine to make a major impact on climate change and its prevention" (Somner et al., 2008, p. 214).

Jones (2009) conducted a similar study, collecting water from the drains of three different types of scrub bays—one with an elbow-controlled tap, one with a spring-loaded foot-controlled tap, and one with a motion-sensor-controlled tap—used in a standardised five-minute scrub routine. He found that when the water flow was turned off between rinses, the volume of water consumed was similar across the three types of taps (6.7 to 7.5 L), but only the spring-loaded foot controlled tap turned off automatically between rinses. When motion-sensor-controlled and elbow-controlled taps ran continuously they consumed three times as much water (20.2 and 24.9 L, respectively), and if the elbow-controlled tap was left continuously opened at a high flow rate the amount of water consumed exceeded 50 L per scrub. He concluded, "Surgical scrub staff can have a significant role in reducing the use of potable water supplies. … It could also be reduced at an organisational level by either retrofitting older facilities or, when building new ones, by selecting the most water-sparing plumbing fixtures" (Jones, 2009, p. 320). This study did not explore the energy required to heat the water.

Table 3.8 summarises reported water consumption associated with dialysis and surgical scrubbing.

Table 3.8: Reported water consumption associated with health services and medical care.

Dialysis	Consumes	120 L H_2O per treatment (purified water)	Tarrass et al., 2008
	Consumes	128 L H_2O per treatment (purified water)	Agar, 2010; Agar et al., 2009;
	Consumes	493 - 500 L H_2O per treatment (including reject water)	
	Consumes	801 L H_2O per home dialysis treatment (including reject water)	
Surgical Scrubbing	Consumes	25 - 51 L H_2O per scrub (elbow controlled tap - continuous)	Jones, 2009
	Consumes	7.5 - 11 L H_2O per scrub (elbow controlled tap - intermittent)	
	Consumes	6.7 L H_2O per scrub (foot pedal controlled tap)	
	Consumes	7.5 - 20 L H_2O per scrub (motion sensor controlled tap)	
	Saves	5.7 L H_2O per surgical scrub (knee vs. elbow controlled tap)	Somner et al., 2008

H_2O – water; L – litres

3.3.2(e) Hospitals

Hospitals consume energy to provide lighting, power medical equipment, heat water, and to supply heating and air conditioning (Bujak, 2010; Chirarattananon, Chaiwiwatworakul, Hien, Rakkwamsuk, & Kubaha, 2010; Daschner & Dettenkofer, 1997; Gaglia et al., 2007; Renedo, Ortiz, Manana, Silio, & Perez, 2006; Saidur, Hasanuzzaman, Yogeswaran, Mohammed, & Hossain, 2010). They also produce waste, both in terms of single-use disposable supplies and waste water (Daschner & Dettenkofer, 1997; Karagiannidis, Papageorgiou, Perkoulidis, Sanida, & Samaras, 2010). Finally, there are indirect energy and environmental impacts associated with their purchasing activities (Daschner & Dettenkofer, 1997).

Compared to other non-residential buildings, hospitals consume more energy per square metre (m^2) of floor space due in part to their continuous, 24-hour operations (Gaglia et al., 2007). The reported annual thermal and electrical energy consumption per m^2 of floor space—or 'energy intensity'—of hospitals, clinics and other health facilities is remarkably consistent over both geography and time, ranging roughly between 230 kWh/m^2 to 330 kWh/m^2 (Table 3.9) (Bujak, 2010; Chirarattananon, Chaiwiwatworakul, Hien, Rakkwamsuk, & Kubaha, 2010; Gaglia et al., 2007; Murray, Pahl, & Burek, 2008; Saidur, Hasanuzzaman, Yogeswaran, Mohammed, & Hossain, 2010) with the exception of a single hospital in Spain (Renedo, Ortiz, Manana, Silio, & Perez, 2006). Murray et al. (2008) estimated that for small health facilities in Scotland, this translates into 86 kg/m^2 of CO_2 emissions, but the greenhouse gas emissions of the facilities represented in the other studies could vary substantially from this, depending on their energy mix (electricity, natural gas, etc) and the primary fuel source used by their electricity supplier (coal, hydro, nuclear, etc).

Heating domestic hot water is a particularly noteworthy energy sink for hospitals, accounting for approximately 20% of the energy burden of two Polish hospitals (Bujak, 2010). Thus, the potential water savings from modifying the taps in surgical scrub sinks as described by Somner et al. (2008) and Jones (2009) could also translate into energy savings. Another possible mechanism for reducing energy consumption in hospitals is to purchase equipment with (or convert existing equipment to) variable speed electric motors. Depending on the energy loading for each motor (50%, 75% or 100%), it has been estimated that one hospital in Malaysia could reduce its energy intensity by 20% to 60%, with a concomitant reduction in greenhouse gas emissions ranging from 85 to 138 t of CO_2e annually (Saidur, Hasanuzzaman, Yogeswaran, Mohammed, & Hossain, 2010).

Table 3.9: Energy intensity of hospitals and other health facilities.

Setting	Annual Energy Intensity	Source
Greece, 1980 (hospitals, health centres & clinics)	235 kWh/m^2	Gaglia et al., 2007
Greece, 2001 (hospitals, health centres & clinics)	233 kWh/m^2	
Greece, 2010 [estimated] (hospitals, health centres & clinics)	236 kWh/m^2	
Scotland, 2001 (small health buildings)	310 kWh/m^2	Murray et al., 2008
Poland, 2005-2008 (university hospital, heat/hot water only)	268 kWh/m^2	Bujak, 2010
Poland, 2005-2008 (provincial hospital, heat/hot water only)	327 kWh/m^2	
Malaysia, 2008 (public hospital)	234 kWh/m^2	Saidur et al., 2010
Spain, ~2005 (hospital, total)	494 kWh/m^2	Renedo et al., 2006
Spain, ~2005 (hospital, electricity only)	169 kWh/m^2	
Thailand, ~1996-2006 (average of 79 hospitals, electricity only)	149 kWh/m^2	Chirarattananon et al., 2010

kWh = kilowatt hour; m^2 = square metre

New hospitals and health facilities can also reduce their energy consumption through design measures that accentuate natural ventilation and reduce the need for air conditioning (Lomas & Ji, 2009), and through compliance with modern building energy codes (Chirarattananon, Chaiwiwatworakul, Hien, Rakkwamsuk, & Kubaha, 2010).

Hospitals can also supplement their energy needs with on-site power generation, which can both produce cost savings (Bizzarri & Morini, 2004; Lozano, Ramos, Carvalho, & Serra, 2009; Renedo, Ortiz, Manana, Silio, & Perez, 2006) and reduce greenhouse gas emissions (Bizzarri & Morini, 2004; 2006). Fuel cells that convert chemical energy into electricity (Bizzarri & Morini, 2004; 2006; Damberger, 1998), solar collectors that use fluid-filled piping to capture the sun's heat (Bizzari & Morini 2006; Tsoutsos, Aloumpi, Gkouskos, & Karagiorgas, 2010), and photovoltaic solar collectors that directly convert solar energy to electricity (Bizzari & Morini, 2006) have all been advocated as on-site power generation technologies that hospitals can use to reduce their consumption of commercial energy and lower their greenhouse gas emissions. The payback time on the initial investment, however, currently makes these strategies economically non-viable: the most optimistic estimate is 11.5 years (Tsoutsos et al., 2010) with most estimates ranging between 20 and 30 years (Bizzari & Morini, 2004; 2006), which far exceeds the usable life of the proposed systems.

3.3.2(f) Ancillary Health System Activities

Research: In 2007, under the moniker 'The Sustainable Trials Study Group', Burnett et al. (2007) evaluated the emissions associated with the Corticosteroid Randomisation after Significant Head Injury (CRASH) Trial evaluating the effect of corticosteroid administration on outcomes of adults with head injury. Based at the

London School of Hygiene and Tropical Medicine, the five-year trial recruited 10,008 subjects from 49 nations. Using the protocol recommended by the World Business Council for Sustainable Development, the investigators estimated emissions associated with fuel use, refrigerant loss and electricity consumption at the trial coordinating centre, fuel use for deliveries and travel, and waste disposal for one year of the trial. Emissions totalled 126 t of CO_2e; the investigators extrapolated emissions for the full five year trial to be 630 t of CO_2e, or approximately 63 kg of CO_2e per study subject. The coordination centre was responsible for 39% of the emissions, with nearly all of its emissions arising from electricity consumption. Distribution of study medications and documents was responsible for 28% of the emissions, and study-related travel accounted for 23%. Trial team commuting and shipping of study drugs from the producer to the coordinating centre were responsible for the remaining 10% of emissions. The investigators concluded, “Clinical trials are energy intensive and produce substantial greenhouse gas emissions” (Burnett et al., 2007, p. 672). They further recommended that the “…research community must ensure that trials look at questions of greatest priority using methods compatible with broader strategic objectives in relation to environment and health” and “… establish awareness about the broader consequences of health care and research…” (Burnett et al., 2007, pp. 672-673). More recently, the CRASH investigators reported they were able to substantially reduce study-related emissions in the CRASH-2 trial, primarily through increased efficiency in subject recruitment (Subaiya, Hogg, & Roberts, 2011).

Telemedicine: Telemedicine is the practice of using internet-based audio-visual links to provide patient consultations to sites where physicians, specialist physicians, and/or other health professionals are not available. In a letter to the British Medical Journal, Smith, Patterson, & Scott (2007) described three examples of telemedicine—

one providing paediatric burn consultations in Australia, one used by a U.K. neurologist to conduct rural clinics, and a hypothetical exploration of the potential to reduce home health nurse visits in Canada. The scale of the effect on greenhouse gas emissions varied greatly, with annual CO_2e reductions of 705 kg for the U.K. neurologist, 29 t for the Australian paediatric burns consultations, and an estimated potential reduction of 33,220 t for home health visits in Canada. The authors concluded that the potential environmental benefits of telemedicine should "…encourage doctors and professional bodies to become more socially responsible by asking whether they could perform some of their current practice virtually" (Smith, Patterson, & Scott, 2007, p. 1060). Unfortunately the Canadian data is not referenced, and while the same research efforts might be the source of the information, the cited articles purportedly describing the experiences of the U.K. neurologist and the Australian burns unit do not actually contain the emissions data reported in the letter (Patterson, 2005; Smith, Kimble, O'Brien, Mill, & Wootton, 2007).

More recently, physicians at the University of California-Davis described their five-year experience providing telemedicine consultations involving more than 13,000 outpatients and 30 different medical specialties (Yellowlees, Chorba, Parish, Wynn-Jones, & Nafiz, 2010). They speculated that the travel avoided by offering that service resulted in savings of more than 700,000 L of petrol and 1,700 t of CO_2 emissions.

In a report on the British Medical Association's recommendation for the NHS to reduce its greenhouse gas emissions, Mayor (2008, p. 740) notes that "[f]ive percent of the U.K.'s road transport emissions are attributed to NHS related journeys by staff, patients, and visitors…", and cites the Royal Cornhill Hospital's use of telemedicine to reduce both patient and staff travel as an example of good practice that helps to avoid emissions.

While none of these telemedicine-related publications are research reports per se, they do raise the intuitive point that telemedicine could reduce travel and thus emissions. They do not, however, take into account the complete life cycle emissions associated with producing telemedicine equipment, renovating or building new clinical spaces to accommodate telemedicine activities, and the electricity required to operate telemedicine services.

Professional Meetings: Three letters have been published in the medical literature addressing attendance at medical conferences. Crane & Caldwell (2006) lamented Crane's attendance at the 16th annual conference of the European Respiratory Society, estimating the conference was responsible for 3,920 t of travel-related CO_2e emissions, used 36.2 t of 'trees' to produce the conference abstract book, and produced uncalculated waste. Callister & Griffiths (2007) calculated travel-related emissions for attendees at the American Thoracic Society's annual International Conference. They estimated the 14,914 delegates who attended the 2006 conference in San Diego, California were responsible for 10,779 t of CO_2e emissions; travel-related emissions from previous conferences in various North American cities were estimated to range from 7,813 t (Toronto, Ontario) to 10,870 t (San Francisco, CA). Hudson (2008) raised concerns about Australian and New Zealand surgeons holding their conference in Hong Kong, China, and the 4.3 t of CO_2e per passenger emitted by a return flight between Sydney and the host city. All of these authors called on organisations and individuals to purchase carbon offsets for their meeting-related travel. In an editorial on the topic, Roberts & Godlee (2007) argued that there is scant evidence that attending medical conferences improves practice, implicitly questioning whether the environmental impact of conference attendance can be justified. Calling on doctors to 'lead by example', they too identified purchasing of carbon offsets, as well as the use of video conferencing, as ways to minimise the environmental impact of medical conferences.

Specialty Training: While not scientifically robust, Hewitt (2008) raised the spectre of the environmental impact of the process of applying for specialty training placements in general surgery. Considering printer paper, application forms, printer cartridges, electricity and transport of the applications by the post office, she anecdotally estimated that process resulted in 480 kg of CO_2 emissions for herself alone.

3.3.2(g) The Role of Nursing

No studies specifically addressed energy consumption or emissions associated with nursing services, which is understandable given that nursing care is typically delivered as a component of medical care rather than as a stand-alone service. The nursing profession, however, has engaged on these issues. Nine (64%) of the fourteen news items identified by this search, plus one of the editorials, specifically targeted nurses and the role they could play in reducing energy consumption and emissions in their professional functions (Anonymous, 2010; Blakemore, 2009; Griffiths, 2008; Moore, 2009; 2010), by setting examples for their patients (Duffin, 2010), and even in their personal lives (Bain, 2009; Holyoake, Wheatley, Brown, & Chapman, 2007; Wallis, 2009).

3.4 Discussion

The energy consumption of hospitals and other health facilities is the only aspect of health-related energy consumption and emissions that has been subjected to rigorous evaluation. Most of that work has been undertaken by researchers outside of the health disciplines: environmentalists; engineers; architects. Hospitals and health clinics are energy intense buildings (Bujak, 2010; Chirarattananon, Chaiwiwatworakul, Hien, Rakkwamsuk, & Kubaha, 2010; Gaglia et al., 2007; Murray, Pahl, & Burek, 2008; Renedo, Ortiz, Manana, Silio, & Perez, 2006; Saidur, Hasanuzzaman, Yogeswaran, Mohammed, & Hossain, 2010), both because of the energy intensity of medical equipment and because they operate 24 hours a day. While on-site energy generation using chemical fuel cell or solar technologies can reduce hospital-related emissions, currently those technologies are not economically viable unless government subsidies are available to offset their initial costs (Bizzari & Morini, 2004; 2006; Tsoutsos, Aloumpi, Gkouskos, & Karagiorgas, 2010).

The health sector otherwise is not widely represented in empirical studies of energy consumption and greenhouse gas emissions, despite widespread advocacy for action and leadership among physicians and other health professionals (Butler, 2010; Kefford, 2006; Santa Barbara 2006; Sarfaty & Abouzaid, 2009; Sellman & Hamilton 2007; Simpson 2008; Woodruff, McMichael, & Hales, 2006). The most sophisticated analysis of health-related emissions to date was undertaken by NHS England, demonstrating that the service was responsible for 21.3 Mt of CO_2e emissions in 2004, or 3% of national emissions (Sustainable Development Commission-Stockholm Environment Institute, 2008). A more cursory evaluation estimated U.S. health services were responsible for 454.5 Mt of CO_2e emissions in one year, or 8% of national emissions (Chung & Meltzer, 2009). On a per-capita basis, health related emissions in these two countries were markedly different: with a population of 50 million during the year of study (2004), London’s health-related emissions were about 420 kg per person; with a study year (2007) population of 301 million, U.S. health-related emissions were about 1,810 kg per person. While this difference might be partly attributable to differences in the structure of health services in these two countries, some (but not all) of the difference might also be an artefact of using input-output analysis and emissions per unit of expenditure to calculate their respective carbon footprints. Per-capita health expenditures in the U.S. are roughly 240% higher than in the U.K. (Organisation for Economic Co-operation and Development, 2010).

The reported emissions from health-related activities are summarised in Table 3.10. The current evidence is almost entirely based on small narrowly focused studies, and to some extent on methodologically weak or anecdotal reports. Still, the data do indicate that per-patient or per-treatment emissions are relatively modest. Even when extrapolating these emissions to national or global patient visits, are health related emissions significant enough to warrant attention? These numbers pale in comparison to global emissions: 49 billion t of CO_2e in 2004 (Intergovernmental Panel on Climate Change, 2007).

Indeed, national greenhouse gas inventories typically only identify the four IPPC ‘Annex A’ economic sectors required under the Kyoto Protocol: Energy Generation (fuel combustion and fugitive emissions); Industrial Processes; Waste; and Agriculture (Australian Government Department of Climate Change, 2009b)—and notably *not* health care. However, emissions from health services are comparable to those of other important economic sectors. In the U.S., for example, emissions from the ‘Agriculture’ sector total approximately 500 million metric tons of CO_2e annually, representing around 7% of total national emissions (U.S. Environmental Protection Agency, 2011). The ‘Waste Management’ sector is responsible for approximately 3% of total emissions in the U.K. (Department of Energy and Climate Change, 2011).

Table 3.10: Reported greenhouse gas emissions from health services and medical care.

Service / Procedure	Impact		Source
Emergency Medical Services	Emit	36.6 – 45.5 kg of CO_2e per ambulance response (North America)	Blanchard & Brown, 2011
Health Systems	Emits	21.3 Mt CO_2e per year (England)	SDC-SEI, 2008
	Emits	545.5 Mt CO_2e per year (United States)	Chung & Meltzer, 2009
Surgical Reflux Control	Emits	1,081 kg CO_2e per patient, + 30.8 kg CO_2e per year thereafter	Gatenby, 2011
Medical Reflux Control	Emits	164 kg CO_2e per patient, + 100 kg CO_2e per year thereafter	
Cataract Surgery	Emits	37.3 kg CO_2 per operation (business as usual)	Somner et al., 2009
	Emits	7.5 kg CO_2 per operation using a 1-stop strategy	
	Avoids	29.8 kg CO_2 per operation using 1-stop vs. business as usual	
Laparoscopic Surgery	Emits	0.23 kg CO_2 per operation (from CO_2 gas cylinders)	Gilliam et al., 2008
Anaesthetic Gases	Emit	7 - 187 kg CO_2e per hour of administration	Ryan & Nielsen, 2010
Small Health Buildings	Emit	86 kg CO_2e/m^2 annually	Murray et al., 2008
Hospitals Wards	Emit	48 - 171 kg CO_2e/m^2 annually (varies by ventilation system)	Lomas & Ji, 2009

*anecdotal or inferred data; CO_2 – carbon dioxide; CO_2e – carbon dioxide equivalent; kg – kilogram; m^2 – square metre; Mt – million tonnes; SDC-SEI – Sustainable Development Commission-Stockholm Environment Institute

Table 3.10 (continued): Reported greenhouse gas emissions from health services and medical care.

Service / Procedure	Impact		Source
Clinical Trials	Emit	63kg CO_2e per participant	Burnett et al., 2007
	Emit	324 kg CO_2e per primary endpoint event	
Telemedicine	Avoids	39 kg CO_2 per consultation	Smith, Patterson, & Scott, 2007*
	Avoids	2.9 kg CO_2e per home health visit avoided	
	Avoids	131 kg CO_2 per consultation	Yellowlees et al., 2010*
Medical Society Meetings	Emit	723 kg CO_2e per participant (American Thoracic Society)	Callister & Griffiths, 2007*
	Emit	227 kg CO_2e per participant (European Respiratory Society)	Crane & Caldwell, 2006*
	Emit	4.3 t CO_2e per international flight (ANZ College of Surgeons)	Hudson, 2008*
Specialty Training	Emits	480 kg CO_2e per applicant	Hewitt, 2008*

*anecdotal or inferred data; CO_2 – carbon dioxide; CO_2e – carbon dioxide equivalent; kg – kilogram; m^2 – square metre; Mt – million tonnes

The juxtaposition of total Australian national emissions with U.S. health care sector emissions is also instructive when considering this point. In 2007 and 2008, Australia’s greenhouse gas emissions totalled 547 Mt and 553 Mt of CO_2e, respectively (Australian Government Department of Climate Change, 2009b). That is, U.S. health sector emissions are of the same scale as Australia’s total national emission. While reducing health-related emissions alone will not solve all of the problems around GHGs and climate change, it can make a meaningful contribution: a 10% reduction in emissions from just the U.S. health system would have the same atmospheric impact as a 10% reduction in emissions from the entire Australian economy. Numerous authors have described how reducing atmospheric CO_2 levels and mitigating climate change will only succeed through the cumulative energy and emissions savings of many such incremental policy initiatives and efforts (e.g.: Coontz, 2007; Lenzen & Smith, 1999/2000; McCollum & Yang, 2009; Mulugetta, Jackson, & van der Horst, 2010; Pacala & Socolow, 2004; Reynolds, 2010; Scholes, 2009).

Some health systems are already taking steps to minimize their environmental impact, most notably the systematic efforts of NHS England (Brockway, 2010). A recent survey of 14 directors of primary care trusts in southwest England found that seven were pursuing sustainability strategies, including the sourcing of green energy, green travel policies such as supporting cycling to work, procurement policies designed to minimize packaging and waste, and the sourcing of local food products for cafeterias (Nichols & Richardson, 2011). Other logical steps that health systems could take to reduce their energy consumption and greenhouse gas consumption include, for example, incorporating natural ventilation and green building concepts when constructing or renovating health facilities (Bizzarri & Morini, 2006;

Chirarattananon, Chaiwiwatworakul, Hien, Rakkwamsuk, & Kubaha, 2010; Lomas & Ji, 2009) or including more hybrid vehicles in the corporate fleet (Hawkins, 2008). Lastly, health systems and health professionals should not underestimate their potential influence on broader sustainability efforts; their stature within the community makes them ideal advocates and role models.

A more practical and perhaps more immediate concern is how mounting energy scarcity, increasing energy costs, and societal pressures to reduce emissions might actually pose a threat to the delivery of health services. Thus, understanding the energy consumption and emissions associated with health services is important not only to identify opportunities to minimise the environmental impact of those services, but also to identify the energy and emissions-related threats to those services in order to better guide their adaptation to a low-carbon economy. Managing greenhouse gas emissions is managing energy consumption, and vice-versa. It is a ‘win-win’ proposition.

3.5 Summary of Health Service Energy Consumption and Emissions

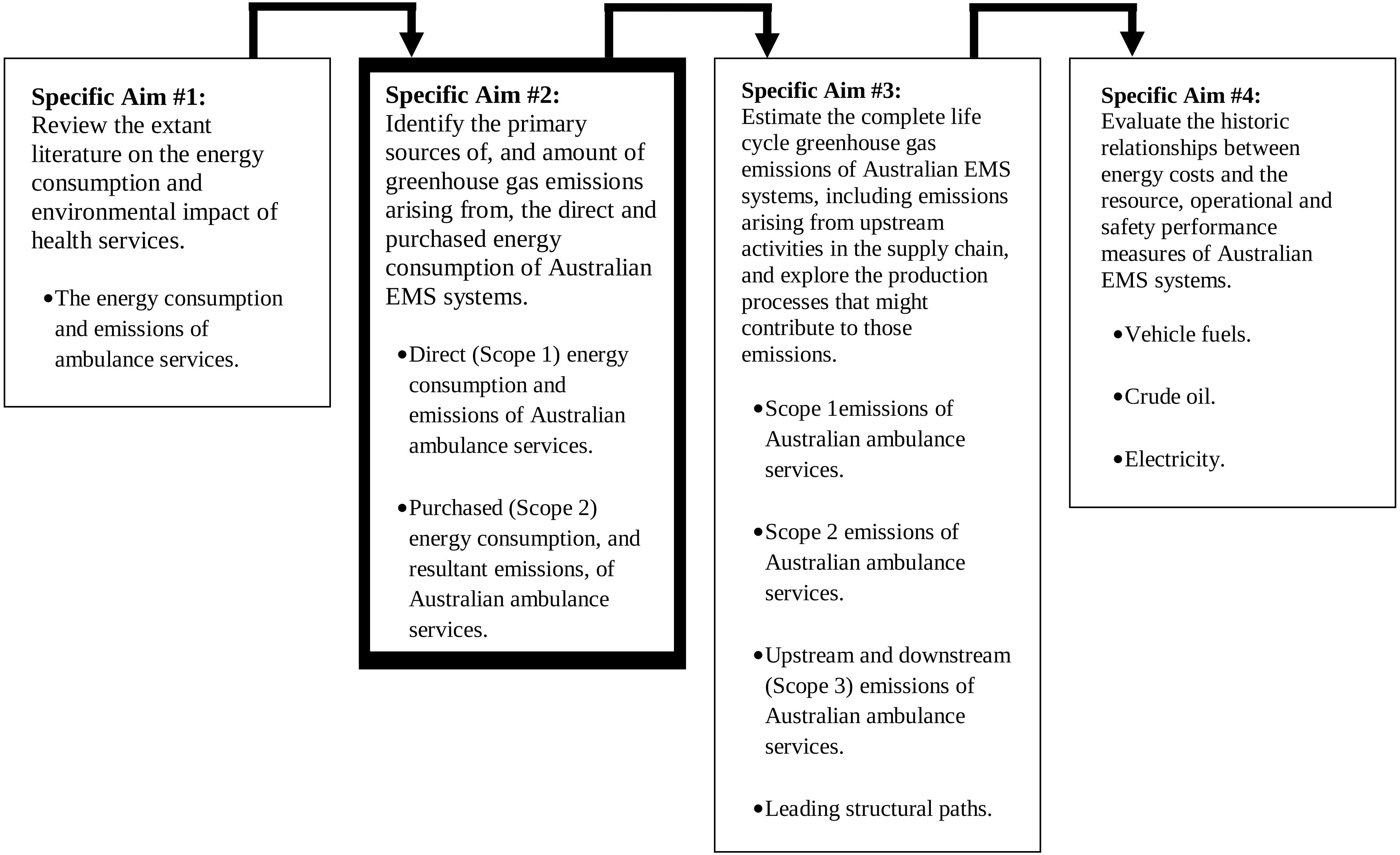
The health sector is not well represented in the energy- and emissions-related literature. The only report a of sector-wide effort to inventory health-related greenhouse gas emissions comes from NHS England, where health services were estimated to produce 21.3 Mt of CO_2e in 2004, or 3% of national emissions for that year (Sustainable Development Commission-Stockholm Environment Institute, 2008). In the U.S., health services are estimated to be responsible for 454.5 Mt of CO_2e emissions each year, or 8% of national emissions (Chung & Meltzer, 2009).

The only reports of energy consumption and emissions from EMS systems are those from the North American studies related to, but not included as part of, this thesis. There, ambulance services are estimated to produce between 36.6 and 45.5 kg CO_2e of Scope 1 and Scope 2 greenhouse gas emissions per ambulance response. The next chapter begins the process of determining the environmental burden of ambulance services in Australia by inventorying their Scope 1 and Scope 2 energy consumption, and calculating the resultant greenhouse gas emissions.

Chapter 4: The Carbon Footprint of Australian Ambulance Operations

Chapter 2 laid out the theoretical and methodological framework for this thesis, and Chapter 3 reviewed the extant literature on health-related energy consumption and greenhouse gas emissions. This chapter describes the effort to determine the Scope 1 and Scope 2 emissions of Australian ambulance systems (Figure 4.1).

This chapter has been adapted into a manuscript: Brown L.H., Canyon, D.V., Buettner, P.G., Crawford, J.M., Judd, J, on behalf of the Australian Ambulance Emissions Study Group. (In Press). The carbon footprint of Australian ambulance operations. *Emergency Medicine Australasia*. Accepted 15 May 2012. Documentation of acceptance is included in Appendix 2.



Specific Aim #1:
Review the extant literature on the energy consumption and environmental impact of health services.

- The energy consumption and emissions of ambulance services.

Specific Aim #2:
Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

- Direct (Scope 1) energy consumption and emissions of Australian ambulance services.
- Purchased (Scope 2) energy consumption, and resultant emissions, of Australian ambulance services.

Specific Aim #3:
Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute to those emissions.

- Scope 1emissions of Australian ambulance services.
- Scope 2 emissions of Australian ambulance services.
- Upstream and downstream (Scope 3) emissions of Australian ambulance services.
- Leading structural paths.

Specific Aim #4:
Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

- Vehicle fuels.
- Crude oil.
- Electricity.

Figure 4.1: Progress through the thesis: Specific Aim #2.

4.1 Abstract

The objective of this study is to determine the greenhouse gas emissions associated with the direct and purchased energy consumption of Australian ambulance operations, and to identify the predominant energy sources that contribute to those emissions. This two-phase study uses operational and financial data from a convenience sample of Australian ambulance operations to inventory their energy consumption and greenhouse gas emissions for one year. State- and territory-based ambulance systems serving 58% of Australia's population and performing 59% of Australia's ambulance responses provided data for the study. Emissions for the participating systems total 67,390 t of CO_2e for the study period, or 35 kg CO_2e per ambulance response, 48 kg CO_2e per patient transport, and 5 kg CO_2e per capita. Vehicle fuels account for 58% of the emissions from ground ambulance operations, with the remainder primarily attributable to electricity consumption. Emissions from air ambulance transport are nearly 200 times those for ground ambulance transport. On a national level, emissions from Australian ambulance operations are estimated to be between 110,000 and 120,000 t of CO_2e each year.

4.2 Introduction

The literature review in Chapter 3 established that the greenhouse gas emissions from individual medical procedures or health services are modest, but in the aggregate they are substantial. Health sector emissions account for 3% of all greenhouse gas emissions in the U.K. (Sustainable Development Commission-Stockholm Environment Institute, 2008), and 8% of greenhouse gas emissions in the U.S. (Chung & Meltzer, 2009). The contribution of individual health-related services to Australian national greenhouse gas emissions has not been empirically studied. To characterise the emissions associated with ambulance operations in Australia, this study addressed two questions: (1) What are the Scope 1 and Scope 2 greenhouse gas emissions associated with Australian ambulance operations? and (2) What energy sources are the primary contributors to the Scope 1 and Scope 2 greenhouse gas emissions of Australian ambulance operations?

4.3 Methods

4.3.1 Design, Setting and Participants

This study evaluates data from the operational and financial records of a convenience sample of Australian ambulance operations. The study was conducted in two phases: a pilot phase evaluating test-retest consistency of the data collection process, and a final phase with full data collection and analysis.

As described in Chapter 2, greenhouse gas emission inventories are typically classified by their ‘scope’. Scope 1 emissions are those that arise from direct energy consumption, for example the burning of petrol in vehicles or natural gas in furnaces. Scope 2 emissions are those that arise from purchased energy consumption, primarily relating to electricity consumption but also including emissions from travel on commercial carriers. Scope 3 emissions are those that arise from a product or service’s upstream and downstream production and waste disposal processes. Finally, ‘complete life cycle emissions’ represent the sum of Scope 1, Scope 2 and Scope 3 emissions (Australian Government Department of Climate Change, 2009a). This study explored the Scope 1 and Scope 2 emissions of Australian ambulance operations.

In Australia, responsibility for ambulance services rests with each state or territory government; ambulance services are provided by agencies within the department of health (New South Wales (NSW); South Australia (SA); Tasmania

(TAS); Victoria (VIC)) or the department responsible for emergency services (Australian Capital Territory (ACT); Queensland (QLD)), or through a contract with St. John's Ambulance Service—an independent not-for-profit organisation (Northern Territory (NT); Western Australia (WA)). In the 2009-2010 fiscal year, Australian ambulance services performed more than 3.5 million emergency and non-emergency responses (Council of Ambulance Authorities, 2010). The ambulance systems of four Australian states or territories participated in this study: Ambulance Service New South Wales (NSW); St. John Ambulance - Northern Territory (NT); SA Ambulance Service (SA); and Ambulance-Victoria (VIC). Three of the systems participated in the pilot phase and three systems provided data for the final phase; two systems participated in both phases. Collectively, the three systems providing data for the final phase of the study served 58% of Australia's population and performed 59% of Australia's ambulance responses during the study period (Council of Ambulance Authorities, 2010).

4.3.2 Pilot Phase Protocol

For the pilot trial, a data collection tool was developed based on the methodology used in the North American study of ambulance-related emissions (Blanchard & Brown, 2011) and with input from the representatives of the participating Australian ambulance systems. The pilot trial data collection tool asked participants to report their agency's energy consumption for a 90-day period during 2009, including: diesel and petrol for ambulances and other vehicles; on-site energy consumption such as natural gas and electricity usage at stations and offices; aviation fuel use; and employee work-related commercial air travel (e.g., travel to conferences and meetings). After a 45-day wash-out period, the respondents were asked to provide the same data for the same period; the importance of re-collecting the data anew, rather than resubmitting the original data, was emphasised to all participants.

For the pilot trial, an *a priori* decision was made that a less than 10% difference in reported ‘test’ and ‘retest’ energy consumption would indicate acceptable test-retest consistency for the data collection tool. In fact, the ‘test’ and ‘retest’ data were nearly identical, except that a small amount of compressed natural gas (CNG) consumption (197 L) reported in the ‘test’ data was reported as liquefied petroleum (LP) consumption in the ‘retest’ data, and there was an error in pro-rata apportionment of natural gas and electricity consumption in one system where some facilities were shared with other agencies. To address this problem, a pro-rating worksheet was developed and distributed with the data collection tool for the final phase of the study.

4.3.3 Final Phase Protocol

The final version of the data collection tool and pro-rating worksheet are included as Appendix 7. For the final phase of the study, participants were asked to report their agency’s energy consumption for a full 12-month period: the most recent calendar year or financial year for which complete data were available. Participants were also asked to report their agency’s call volume for the same period, including total number of responses, number of emergency responses, and number of patients transported. The population served by each agency was obtained from the Australian Bureau of Statistics (2011).

4.3.4 Data Analysis

All data were converted into standard units: L for liquid fuels, GJ for natural gas, and kWh for electricity. For each reported energy source, emissions of CO_2e per unit of consumption were calculated using Australian government 'National Greenhouse Accounts' emission factors (Australian Government Department of Climate Change, 2009c). Aggregate emissions for the participating agencies, as well as emissions per response, per patient transport, and per capita (that is, per person residing in the agencies' respective service areas), are reported. The contributions of individual energy sources to the total emissions, and the differentiation of emissions from ground and air ambulance activities, are also reported.

4.4 Ethical Review

The Human Research Ethics Committee (HREC) at James Cook University approved this study (HREC #H3592, Appendix 1) with the understanding that all data would be reported in the aggregate. The study was also approved by the research committee, research director, or managing director of each participating agency.

4.5 Results

The emissions from the reported energy consumption for the three ambulance systems participating in the final phase of the study totalled 67,390 t of CO_2e. This translates into 35 kg CO_2e per ambulance response, 48 kg CO_2e per patient transport, and 5 kg CO_2e per capita. Diesel and petrol consumption were responsible for 35% of the emissions; electricity consumption was responsible for 26% of the emissions; and aviation fuel consumption was responsible for 38% of the emissions. Other fuel sources accounted for less than 1% of total emissions (Figure 4.2).

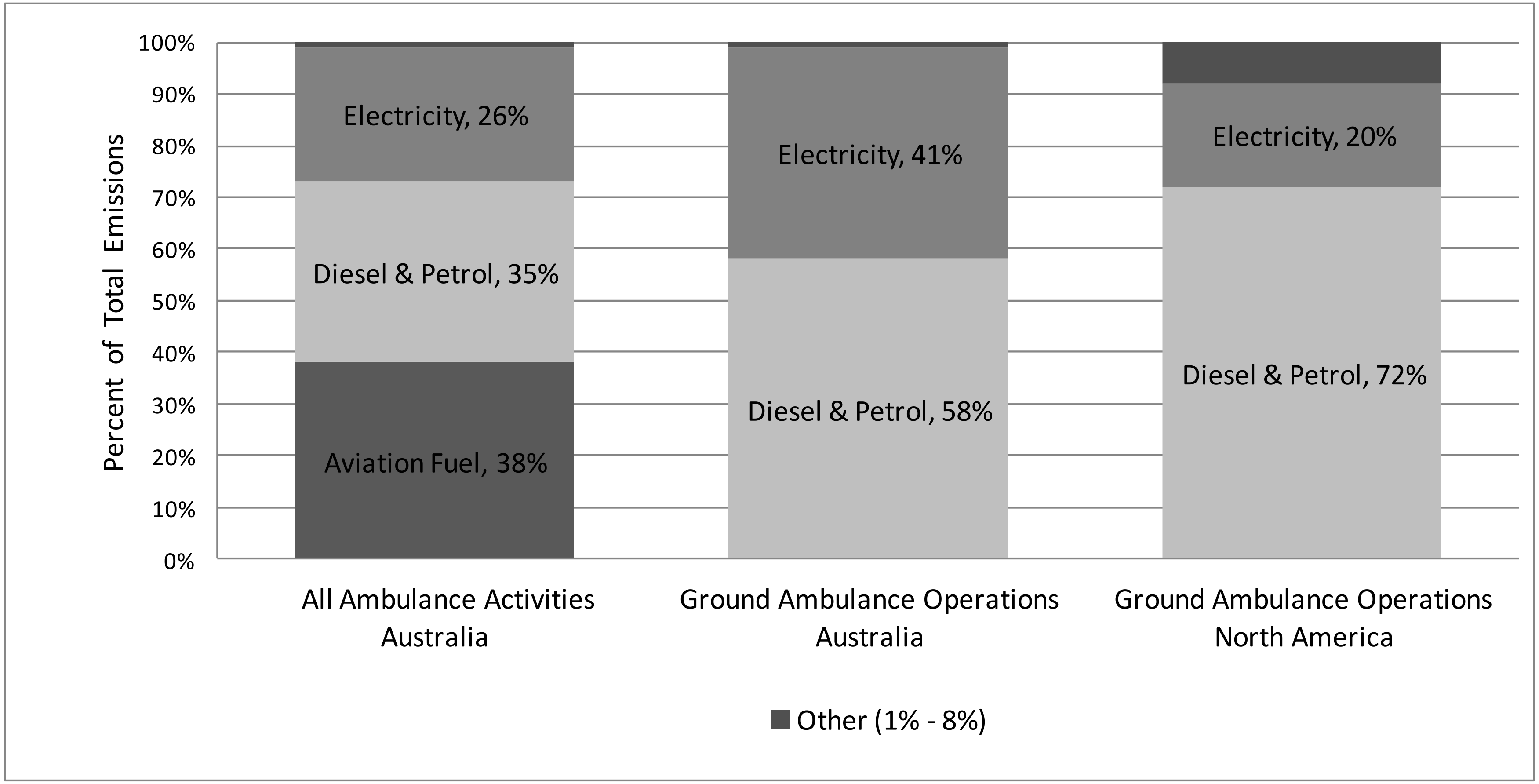


Figure 4.2: Primary sources of Australian ambulance services' greenhouse gas emissions, and comparison with reported North American data (Blanchard & Brown, 2011).

Only two of the participating systems provided air ambulance services and, in both systems, air ambulance missions represented less than 1% of all patient transports. When eliminating aviation fuel consumption and air ambulance missions from the analysis, ground ambulance operations in the three participating systems generated 41,885 t of CO_2e emissions for the study period. This equates to 22 kg CO_2e per ground ambulance response, 30 kg CO_2e per patient transport, and 3 kg CO_2e per capita. Diesel and petrol consumption were responsible for 58% of the emissions from ground ambulance activities, with electricity consumption responsible for 41% of the emissions (Figure 4.2). Emissions from aviation fuel for the two systems providing air ambulance services totalled 25,505 t of CO_2e, or 5.3 t CO_2e per air ambulance mission and 5.8 t CO_2e per patient transport.

4.6 Discussion

Consistent with other research on health service emissions, per-patient greenhouse gas emissions from Australian ground ambulance operations are small. However, extrapolating these results to the entire nation (5 kg per capita × 22 million population; 35 kg per response × 3.5 million ambulance responses) suggests aggregate Scope 1 and Scope 2 emissions from Australian state- and territory-based ground and air ambulance operations total approximately 110,000 to 120,000 t of CO_2e each year. As Australia’s national emissions approach 550 to 560 Mt annually (Australian Government Department of Climate Change, 2009b), Scope 1 and Scope 2 emissions from ambulance operations represent 0.02% of the country’s total greenhouse gas emissions. This might seem like a small proportion, but the Australian economy is divided into 19 divisions, 53 subdivisions, 214 industry groups, and finally 506 industry classes—including ambulance services (Australian Bureau of Statistics, 2006). The estimated Scope 1 emissions from ambulance services (81,000 to 89,000 t CO_2e) are comparable to the direct greenhouse gas emissions from the ‘brown coal’ (93,000 t) or ‘silver and zinc’ (89,000 t) mining sectors reported in a 2005 analysis of the Australian economy (Foran, Lenzen, & Dey, 2005).

Encouragingly, the average per-response emissions for Australian ground ambulance operations are half those reported for North American ambulance systems (22 kg vs. 45 kg CO_2e) and the contribution of vehicle fuels to the carbon footprint of Australian ambulance systems is not as great as for North American systems, 58% vs. 72% (Figure 4.2) (Blanchard & Brown, 2011). This might reflect differences in the geographical distributions of the populations on the two continents: While Australia is less densely populated than the U.S. (2.9 people / km^2 vs. 33.7 people / km^2), only 12% of the Australian population live outside of urban areas, compared with 21% of the U.S. population (Australian Bureau of Statistics, 2011; U.S. Census Bureau, 2011). It could be a function of the efficiency of the vehicle fleet; light weight van-chassis ambulances are more common in Australia, while heavier truck-chassis ambulances are more common in North America. There might also be increased efficiencies associated with the centralisation of Australian ambulance operations as state or territory governmental services. In all likelihood, it is some combination of these and other factors.

Despite these favourable comparisons, Australian ambulance operations should still strive to minimise their environmental impact. Potential strategies for reducing ambulance system energy consumption and greenhouse gas emissions include reducing unnecessary ambulance responses and ambulance transports, developing flexible response time policies, reducing driving speeds when transporting stable patients without life-threatening conditions, reduced ambulance idling at emergency scenes and receiving hospitals, the use of hybrid vehicles for administrative and support vehicle fleets, or the use of bio-diesel for ambulances. None of these proposed strategies, however, have been empirically evaluated; their actual impact on energy consumption and emissions, as well as patient outcomes, remains to be determined. For example, while the benefits seem intuitive, bio-diesel is not universally carbon neutral (Searchinger et al., 2008; Solomon, 2010).

Restricting the use of air ambulances, whether rotor-wing or fixed-wing, to only those situations in which they are demonstrated to provide some clinical benefit might also be an intuitive strategy for substantially reducing ambulance system energy consumption and emissions. In this study, average emissions for air ambulance transport were nearly 200 times the average emissions for ground ambulance transport, and emissions for Australian air ambulance missions were approximately five times those of North American air ambulance missions (Blanchard & Brown, 2011). Yet, reducing air ambulance responses and transports in Australia could be a particularly difficult task. Independent of patient clinical condition, many Australian air ambulance missions involve patients in rural or remote locations where access and transport by ground ambulance is simply not feasible, and sometimes not possible.

Finally health promotion initiatives, as well as injury and illness prevention programs, could have a dual effect of improving public health and reducing the demand for ambulance services, and thus ambulance-related emissions.

4.7 Limitations

This study is limited by its focus on only Scope 1 and Scope 2 greenhouse gas emissions. While the Scope 3 emissions of Australian ambulance operations were not explored in this analysis, they would certainly add to the total carbon footprint. In the U.S. and U.K., Scope 3 emissions represent 54% and 60% of total health sector emissions, respectively (Sustainable Development Commission-Stockholm Environment Institute, 2008; Chung & Meltzer, 2009). Like other aspects of the health sector, ambulance services could additionally reduce their total life cycle greenhouse gas emissions by adopting environmentally conscious purchasing strategies.

This study is also limited by its inclusion of data for only three Australian ambulance systems, but the participating systems are geographically and climatically diverse and account for nearly 60% of all ambulance responses in Australia (Council of Ambulance Authorities, 2010). It is also likely that the energy consumption data reported by these three systems slightly under-estimate their true Scope 1 and 2 carbon footprint. Only one system reported employee-related travel, and another system could not access electricity consumption data for approximately 10% of its facilities, as those facilities were shared with—and the electricity billing was in the name of—non-participating third parties. One of the participating systems does not provide ambulance services for people or events more than 150 km from an ambulance station, thus data for that small portion of ambulance responses in that geopolitical setting were not included in this analysis. Still, the participating systems were able to report the vast majority of their energy consumption. The data should be adequately representative of the national experience.

Lastly, the comparisons with the emissions from North American ambulance operations are based on published data from that continent (Blanchard & Brown, 2011), and were not a specific aim of this study. The methodologies of the two studies, however, were nearly identical and the comparisons are sound.

4.8 Conclusion

In summary, per-response emissions from Australian ground ambulance operations are substantially lower than those from North American ambulance operations. Vehicle fuels account for nearly 60% of the emissions from ground ambulance operations, with the remainder primarily attributable to electricity consumption. Emissions from air ambulance transport are nearly 200 times those of ground ambulance transport. Overall, the Scope 1 and Scope 2 energy consumption of Australian state- and territory-based ground and air ambulance operations produces approximately 110,000 to 120,000 t of CO_2e each year, which is of the same order as other important sectors of the Australian economy.

What, though, are the complete life cycle emissions of Australian ambulance services? The next chapter addresses that question.

4.9 Acknowledgements

Contributing members of the Australian Ambulance Services Emissions Study Group:

- Simone L. Darke, Ambulance Victoria, Doncaster, VIC
- Rob Elliott, SA Ambulance Service, Eastwood, SA
- Paul M. Middleton, Ambulance Service of New South Wales, Rozelle, NSW
- Peter J. Monks, St. John Ambulance – Northern Territory, Casuarina, NT
- Robyne Stewart, Ambulance Service of New South Wales, Rozelle, NSW

Chapter 5: The Complete Life Cycle Emissions of Australian Ambulance Services

The previous chapter focused on the Scope 1 and Scope 2 energy consumption and greenhouse gas emissions of Australian EMS systems. Those are the obvious and intuitive issues for EMS agencies, but the upstream energy consumption and emissions associated with the products and services in the ambulance system supply chain should not be ignored. In this chapter, the complete life cycle emissions of Australian EMS systems are explored (Figure 5.1).

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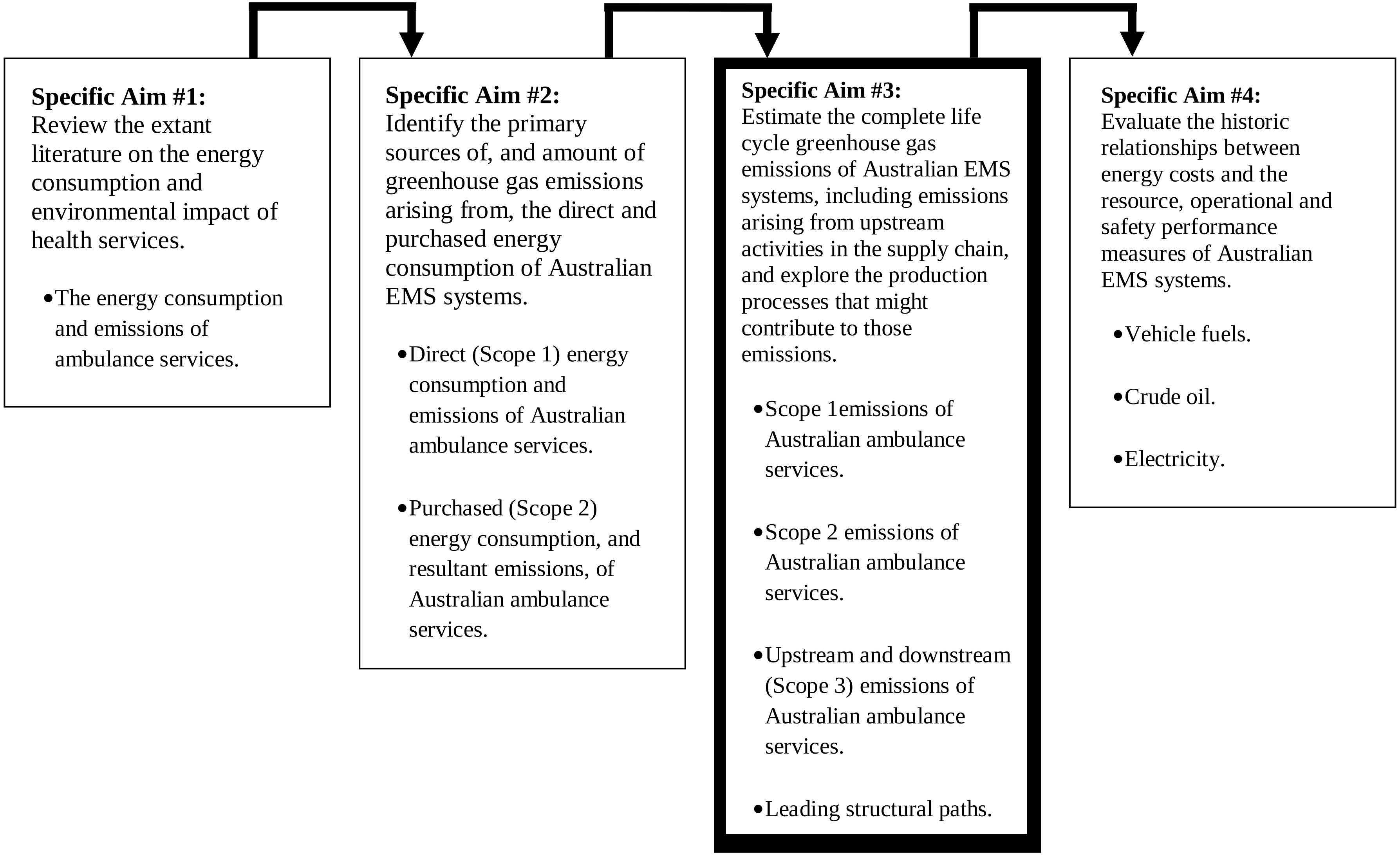


Specific Aim #1:
Review the extant literature on the energy consumption and environmental impact of health services.

- The energy consumption and emissions of ambulance services.

Specific Aim #2:
Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

- Direct (Scope 1) energy consumption and emissions of Australian ambulance services.
- Purchased (Scope 2) energy consumption, and resultant emissions, of Australian ambulance services.

Specific Aim #3:
Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute to those emissions.

- Scope 1emissions of Australian ambulance services.
- Scope 2 emissions of Australian ambulance services.
- Upstream and downstream (Scope 3) emissions of Australian ambulance services.
- Leading structural paths.

Specific Aim #4:
Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

- Vehicle fuels.
- Crude oil.
- Electricity.

Figure 5.1: Progress through the thesis: Specific Aim #3.

5.1 Abstract

Reducing global greenhouse gas emissions will ultimately depend on multiple strategies implemented on international, national, local and institutional or organisational scales. Ambulance services are a vehicle-intense subsector of the health sector that could contribute to that sector's emissions reduction efforts. This analysis uses data from the previous inventory of ambulance service Scope 1 and Scope 2 emissions (Chapter 4), along with publicly available expenditure data and input-output based multipliers, to estimate the complete life cycle emissions of Australian ambulance services. Total emissions are estimated at between 216,000 and 547,000 t CO_2e annually, with approximately 20% arising from direct consumption of vehicle and aircraft fuels, 22% arising from electricity consumption, and 58% arising from upstream Scope 3 processes. The estimates and the leading structural paths differ substantially depending on the extent to which inventory-based versus input-output-based data are incorporated into the estimates, and whether ambulance services' economic structures are presumed to resemble those of broader health sector activities, other emergency services, or general government services. Emissions from ambulance services represent between 1.8% and 4.4% of total Australian health sector emissions, suggesting that ambulance services might indeed play a role in that sector's emissions reduction efforts.

5.2 Introduction

Much of the international emphasis on reducing greenhouse gas emissions has placed responsibility on national governments (Cushman & Jones, 2002; Macintosh, 2010). In reality, however, a country's total emissions are the sum of the emissions from many thousands of relatively low-emitting institutions, firms, and organisations, as well as thousands, millions or—in the case of India and China—billions of individuals.

While national governments might be able to influence the behaviour of organisations, firms and individuals through policy efforts such as green energy initiatives or carbon taxes, reducing global greenhouse gas emissions will ultimately depend on the cumulative successes of multiple strategies implemented on international, national, local, institutional, organisational and individual scales (Cushman & Jones, 2002; Mulugetta, Jackson, & van der Horst, 2010; Pacala & Socolow, 2004; Reynolds, 2010).

Healthcare is one example of an economic sector with substantial total greenhouse gas emissions arising from the aggregation of many low-emitting activities (see Chapter 3). As with global emissions, for the health sector to substantially reduce its total greenhouse gas emissions will require the cumulative efforts of hundreds of component sub-sectors each reducing their emissions on what might appear to be relatively small scales.

Ambulance services are a vehicle-intense subsector of healthcare that might be able to disproportionately contribute to the sector's emissions reduction efforts. In North America, each ambulance response is estimated to produce 36.6 kg (median) to 45.5 kg (mean) CO_2e of Scope 1 and Scope 2 emissions arising from vehicle fuel and electricity consumption (Blanchard & Brown, 2011). In Australia, ground ambulance services emit approximately 22 kg CO_2e of Scope 1 and Scope 2 emissions per ambulance response (See Chapter 4). To date, no attempt to characterise the Scope 3 and complete life cycle emissions of ambulance services has been reported.

This study attempts to estimate the complete life cycle emissions associated with Australian ambulance services through a hybrid assessment incorporating both inventory-based and input-output based emissions estimates. In addition to quantifying the contributions of Scope 1, Scope 2 and Scope 3 emissions in the carbon footprint of Australian ambulance agencies, this study explores the leading structural paths that ambulance services might target in efforts to reduce their greenhouse gas emissions. Finally, this study exemplifies the difficulties associated with using aggregate sectoral input-output based multipliers for estimating emissions from diverse sub-sectoral or cross-sectoral activities.

5.3 Methodology

5.3.1 Data Sources

5.3.1(a) Inventory of Scope 1 and Scope 2 Emissions

Chapter 4 inventoried the Scope 1 and Scope 2 energy consumption and greenhouse gas emissions of Australian ambulance services, duplicating a methodology previously used in a similar assessment of North American EMS agencies (Blanchard & Brown, 2011). To briefly review, three Australian state- or territory-based ambulance systems, serving 58% of the Australian population and performing 59% of all Australian ambulance responses, reported their vehicle fuel, aviation fuel, natural gas and electricity consumption for a 12-month period in 2009-2010. Emission factors from the Australian government's 'National Greenhouse Accounts' (Australian Government Department of Climate Change, 2009c) were then used to calculate the CO_2e emissions associated with that energy consumption. From these data, the Scope 1 and Scope 2 emissions from all Australian ground and air ambulance operations were estimated to total approximately 110,000 to 120,000 t of CO_2e each year, with electricity consumption representing 26% of that total. For this study, the mid-point of that estimate (115,000 t CO_2e) is used as a notional inventory-based estimate of annual Australian ambulance service Scope 1 and Scope 2 emissions, with 85,100 t CO_2e (74%) arising from direct energy consumption and 29,900 t CO_2e (26%) arising from electricity consumption.

5.3.1(b) Input-Output based Multipliers and Structural Path Analyses

Input-output analysis and structural path analysis are both well known and widely described in the ecological- and energy-economics literature. Input-output analysis "… is a top-down macroeconomic technique using sectoral monetary transactions … to account for the complex interdependencies of industries in modern economies" (Lenzen, 2003, p. 3). Leontief (1970) demonstrated that input-output analysis could be used to analyse pollutants (as opposed to monetary transactions) as integral components of economic processes, and since then the technique has been used in numerous studies to determine the resource flows and environmental impacts associated with the final consumption of economic sectors (Wiedmann, Minx, Barrett, & Wackernagel, 2006). Structural path analysis, or decomposition analysis, is the process of 'unravelling' the flows and transactions represented in input-output analyses in order to identify the principal production chains contributing to the final consumption within, and the environmental impacts of, an economic sector (Lenzen, 2002; 2003). Structural paths can be described as 'zero order', resulting from transactions within an individual economic sector, 'first order', resulting from the direct transactions between one economic sector and another, or 'second (and more distal) order' resulting from successive transactions between three (or more) sectors in the production chain.

In 2005, researchers from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of Sydney published a comprehensive 'triple bottom line' (TBL) analysis of the Australian Economy (Foran, Lenzen, & Dey, 2005). Titled 'Balancing Act', this analysis used Australia's 1994-1995 economy-wide input-output tables to develop a TBL accounting for three financial, three social and four environmental indicators for all 135 sectors of the Australian economy. Included in this analysis are TBL multipliers showing the relationship between each of the indicators and gross national expenditure (GNE) or gross national turnover (GNT) within each sector. One of the included multipliers is greenhouse gas emissions in kg CO_2e per dollar of expenditure; this multiplier is further differentiated into a multiplier for direct emissions and a multiplier for total emissions. The ‘Balancing Act’ analysis also identifies the leading structural paths contributing to the greenhouse gas emissions of each economic sector, including their first-order electricity consumption and the proportion of total emissions attributable to that electricity consumption.

Ambulance services in Australia are formally classified as a component of the ‘health services’ economic sector (Foran, Lenzen, & Dey, 2005), but they are delivered by state and territory governments as public goods and they are not universally situated within Departments of Health; in four Australian states and territories ambulance services are either delivered by the departments responsible for other emergency services or function as independent statutory authorities. However they are administratively structured, the operational characteristics of ambulance systems are less like those of, for example, hospitals and more like those of other emergency services such as police departments and fire departments. In Australia, police departments and fire departments are formally classified as components of the ‘other services’ economic sector. Due to this cross-sectoral nature of ambulance services, this analysis incorporates the TBL multipliers and structural paths reported for the ‘health services’ (Hs), ‘government services’ (Gv) and ‘other services’ (Os) sectors of the Australian economy.

Both the direct and total TBL multipliers for the Hs, Gv, and Os sectors, along with the percentage of emissions arising from their first order electricity consumption, are shown in Table 5.1.

Table 5.1: Triple-bottom-line CO2e multipliers (kg per $ GNE/GNT) and first order electricity consumption for the Health Services (Hs), Other Services (Os), and Government services (Gv) sectors of the Australian economy (Foran, Lenzen, & Dey, 2005).

Sector	Direct TBL Multiplier	Total TBL Multiplier	% from 1st Order Electricity Consumption
Hs	0.02	0.15	32%
Os	0.11	0.36	25%
Gv	0.01	0.33	27%

$ = 1994-1995 Australian dollars; CO_2e = carbon dioxide equivalents; GNE = gross national expenditures; GNT – gross national turnover; kg = kilograms; TBL = triple-bottom-line

5.3.1(c) Ambulance Service Expenditures Data

According to the Council of Ambulance Authorities (CAA), state and territory governments spent $2.1 billion delivering 3.5 million ambulance responses in 2009-2010 (Council of Ambulance Authorities, 2010). As these expenditure data are reported in 2008-2009 dollars and the TBL multipliers described above were developed from input-output tables using 1994-1995 dollar amounts, the ambulance expenditure data were adjusted using consumer price index data from the Australian Bureau of Statistics (2012); $2.1 billion in 2008-2009 dollars is equivalent to $1.4 billion in 1994-1995 dollars.

5.3.2 Estimations

The formulas for, and the sequences of, all of the calculations are shown in Table 5.2.

Table 5.2: Calculations used to estimate the complete life cycle emissions of Australian ambulance services.

Estimate	Component	Calculation
I-O only	I-O S1	(TBL 'Direct' Multiplier) × (Expenditures)
	I-O LCA	(TBL 'Total' Multiplier) × (Expenditures)
	I-O S2	(% First Order Electricity / 100) × (I-O LCA)
	I-O S3	(I-O LCA) – [(I-O S1) + (I-O S2)]
Hybrid Approach 1 (H1)	H1 S1	Inventory S1 Determination
	H1 S2&S3	(I-O LCA) - (I-O S1)
	H1 LCA	(H1 S1) + (H1 S2&S3)
	H1 S2	(% First Order Electricity / 100) × (H1 LCA)
	H1 S3	(H1 S2&S3) – (H1 S2)
Hybrid Approach 2 (H2)	H2 S1	Inventory S1 Determination
	H2 S2	Inventory S2 Determination
	H2 S3	(H1 S2&S3) – (I-O S2)
	H2 LCA	(H2 S1) + (H2 S2) + (H2 S3)

H1 = hybrid approach 1; H2 = hybrid approach 2; S2&S3 = total indirect emissions; I-O only = input-output based estimate; LCA = complete lifecycle emissions; S1 = Scope 1 (direct) emissions; S2 = Scope 2 (electricity) emissions; S3 = Scope 3 emissions; TBL = triple-bottom-line

5.3.2(a) Input-Output Based Scope 1, 2 & 3 Emissions Estimates

The complete life cycle emissions of ambulance services were first estimated based solely on the input-output TBL multipliers: once based on the multipliers reported for the Hs sector; once using the multipliers for the Os sector; and once using the Gv sector multipliers. The estimates of total emissions and direct (Scope 1) emissions were calculated as the product of the appropriate TBL multiplier and ambulance service expenditures. The estimates of Scope 2 emissions from electricity consumption were then calculated as the percentage of total emissions arising from first order electricity consumption, as indicated in the respective structural path analyses. Finally, Scope 3 emissions were then calculated as the difference between total emissions and the sum of Scope 1 and Scope 2 emissions.

5.3.2(b) Hybrid Approach 1: Inventory Based Scope 1 and Input-Output Based Scope 2 & 3 Emissions

The first set of hybrid estimates (H1) of ambulance service life cycle emissions assumed that the inventory-based determination of direct emissions was more accurate than the input-output based determinations. For these estimates, the inventory-based determination was used for Scope 1 emissions, while the Hs, Os and Gv TBL multipliers were each used to estimate indirect emissions. Scope 2 emissions from electricity were again estimated as the percentage of total emissions reported for first order electricity consumption in the existing structural path analyses.

5.3.2(c) Hybrid Approach 2: Inventory Based Scope 1 & 2 and Input-Output Based Scope 3 Emissions

The second set of hybrid estimates (H2) of ambulance service life cycle emissions assumed that the inventory-based determinations of both direct emissions and electricity-related emissions were more accurate than the input-output based determinations. For these estimates, the inventory-based determinations were used for both direct (Scope 1) and electricity (Scope 2) emissions. Scope 3 emissions were calculated as the difference between the indirect emissions calculated in the H1 estimates and the electricity emissions estimated using the pure input-output approach.

5.4 Ethical Review

The HREC at James Cook University approved this study (HREC #H4277, Appendix 1) with the understanding that all data and analyses be reported in the aggregate.

5.5 Results

Table 5.3 shows the results of the emissions estimates, as well as the average of all the estimates.

The estimates of annual complete life cycle emissions from Australian ambulance services range from 216,369 t CO_2e to 546,688 t CO_2e; the average of these estimates is 389,315 t CO_2e. On a per-event basis, estimated emissions range from approximately 60kg CO_2e per ambulance response to 150 kg CO_2e per ambulance response, with an average of 110 kg CO_2e per ambulance response. In all of the estimates, the contribution of indirect emissions is substantial, ranging from 63% to 97% of total emissions. On average, indirect (Scope 2 and Scope 3) emissions account for 80% of total estimated emissions.

Figure 5.2 provides a visual display of the emissions estimates. The lowest estimates of complete life cycle emissions from Australian ambulance systems arise from the calculations incorporating TBL multipliers from the Hs sector; emissions estimates based on the Os and GV TBL multipliers are approximately 1.5 to 2.4 times greater than those based on the Hs TBL multipliers, depending on the estimation procedure.

Table 5.3: Estimates of Australian ambulance services' annual greenhouse gas emissions (t CO_2e).

	TBL Multiplier	Scope 1	Scope 2	Scope 3	Total	per response	% Direct	% Electricity	% Indirect
Inventory Based Determination	n/a	**85,100**	**29,900**	n/a	**115,000**	32.6 kg	74%	26%	n/a
I-O Based Estimate	Hs	28,849	69,238	118,282	216,369	61.3 kg	13%	**32%**	87%
	Os	158,671	119,003	198,338	476,012	134.8 kg	33%	**25%**	67%
	Gv	14,425	3,895	500,966	519,286	147.1 kg	3%	**27%**	97%
Hybrid Approach 1 (H1) Estimate	Hs	**85,100**	87,238	100,282	272,620	77.2 kg	31%	**32%**	69%
	Os	**85,100**	111,429	249,186	445,715	126.3 kg	19%	**25%**	81%
	Gv	**85,100**	147,606	313,982	546,688	154.9 kg	16%	**27%**	85%
Hybrid Approach 2 (H2) Estimate	Hs	**85,100**	**29,900**	118,282	233,282	66.1 kg	37%	13%	63%
	Os	**85,100**	**29,900**	230,794	345,794	98.0 kg	25%	9%	75%
	Gv	**85,100**	**29,900**	333,064	448,064	126.9 kg	19%	7%	81%
Mean of I-O, H1 and H2 Estimates	n/a	79,172	69,790	240,353	389,315	110.3 kg	20%	18%	80%

CO_2e – carbon dioxide equivalents; Gv = Government Services; H1 = hybrid approach 1; H2 = hybrid approach 2; Hs = Health Services; I-O = input-output; Os = Other Services; t – tonne; bolded values are extracted from Chapter 4 or Foran, Lenzen & Dey, 2005, non-bolded values are derived from this analysis.

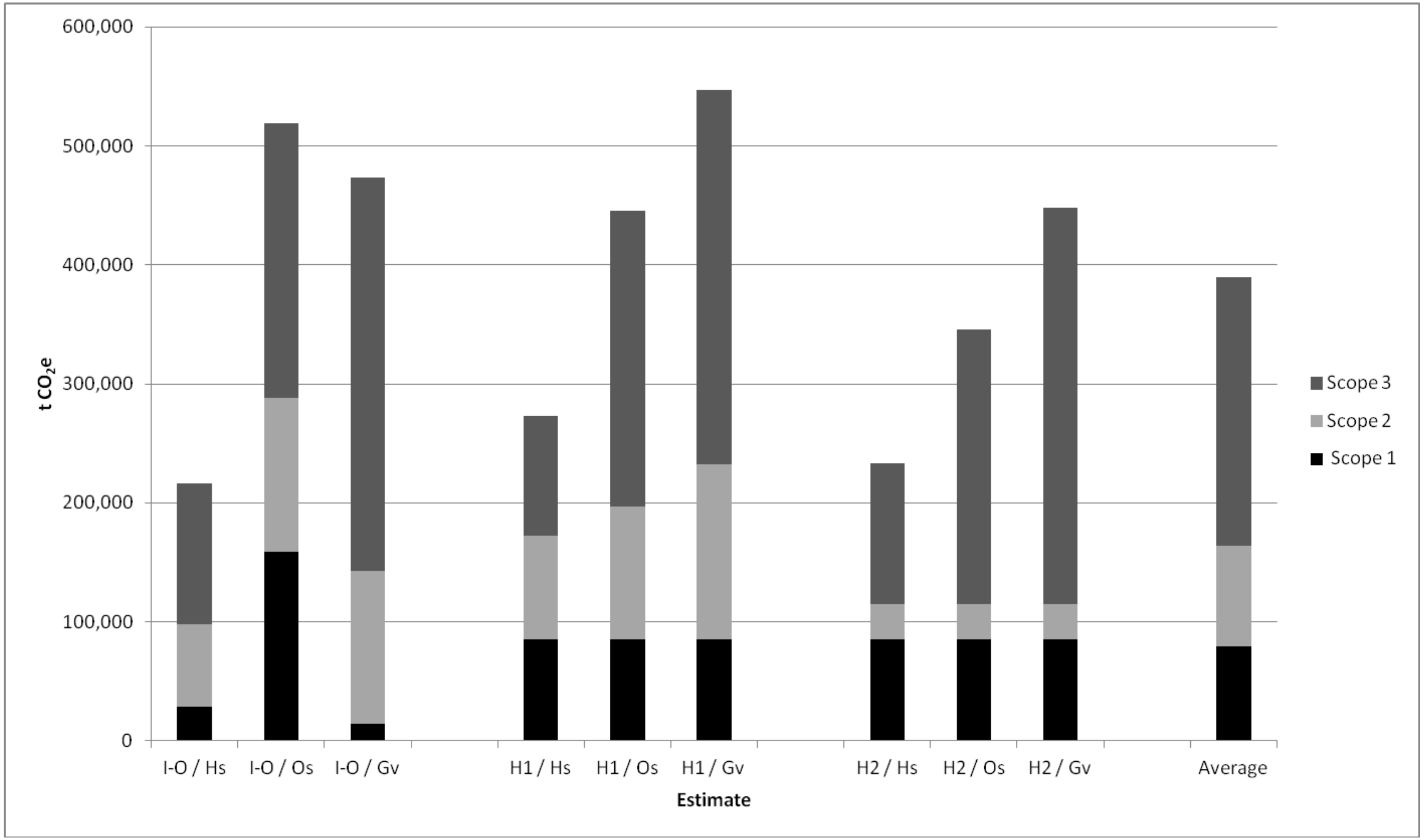


Figure 5.2: Estimated annual Australian ambulance service emissions.

Regardless of the TBL multipliers used, including the inventory-based determination of Scope 2 emissions substantially reduces the proportion of estimated emissions arising from first order electricity consumption. The structural path analyses suggest first order electricity consumption would be responsible for 25% to 32% of total ambulance service emissions; using the inventory based determination of Scope 2 emissions reduces those proportions to between 7% and 13%. On average, electricity consumption is responsible for 18% of estimated ambulance service emissions.

Table 5.4 shows the top five structural pathways for the three economic sectors used in this analysis; in all of these sectors, zero order transactions within the sector and first order electricity consumption are among the top five structural paths. The remaining leading structural paths include some that would be intuitively related to ambulance services—such as chemicals, wholesale trade, and paper products—as well as some that are not intuitive. This is particularly true within the Os sector, where ‘lime’, ‘sheep and shorn wool’ and ‘beef cattle for meat products’ are among the leading structural paths. The top five structural paths account for 53%, 63%, and 37% of emissions estimated using only the input-output based TBL multipliers for the Hs, Os and Gv sectors, respectively.

Table 5.4: Top five structural paths for emissions from the Health Services (Hs), Other Services (Os) and Government Services (Gv) sectors of the Australian economy (Foran, Lenzen, & Dey, 2005).

Hs	*order*; %	Os	order; %	Gv	*order*; %
Health Services	*0*; 15.0	Other Service	*0*; 30.0	Government Services	*0*; 3.2
Electricity	*1*; 32.0	Electricity Supply	*1*; 25.0	Electricity	*1*; 2.7
Basic Chemicals	*1*; 3.7	Lime	*1*; 2.3	Air and Space Transport	*1*; 3.5
Wholesale Trade	*1*; 1.7	Sheep and Shorn Wool	*1*; 1.5	Pulp, Paper and Paperboard	*1*; 1.4
Gas Production and Distribution	*1*; 1.0	Beef Cattle for Meat Products	*2*; 4.2	Softwoods for Pulp, Paper, Paperboard	*2*; 1.4

5.6 Discussion

In the 2009-2010 financial year, Australia's national expenditures on health care totalled $121.4 billion dollars (Australian Institute of Health and Welfare, 2011). Converting this sum to 1994-1995 dollars and applying the health services TBL total emissions multiplier indicates Australian health services were responsible for approximately 12.3 million t of CO_2e emissions in the 2009-2010 financial year. Using the average estimate from this analysis suggests that ambulance services were responsible for 3.2% of all Australian health sector emissions in that year; the best case and worst case estimates of ambulance service emissions are 1.8% and 4.4% of total health sector emissions, respectively. Since ambulance service expenditures ($2.1 billion) represent 1.7% of total health expenditures, all except the most conservative estimates indicate that ambulance services are a disproportionate contributor to health sector emissions. As such, they might play an important role in reducing health sector emissions.

Reducing emissions from vehicle fuel consumption is probably the most obvious strategy ambulance systems could employ to reduce their carbon footprint. In this analysis, direct emissions—primarily from diesel, petrol and aviation fuels—accounted on average for only 20% of all ambulance system emissions. However, when using the inventory based Scope 1 and Scope 2 emissions and assuming that input-output based Scope 3 emissions of ambulance services are consistent with those of the Hs sector (that is, when using the 'H2 / Hs' estimate in Table 5.3 and Figure 5.2), the contribution of emissions from vehicle fuels could be as high as 37% of total emissions. At 3.5 million ambulance responses per year, even marginal reductions in emissions from each individual ambulance response could result in substantial cumulative emissions reductions. Strategies for reducing vehicle fuel consumption and Scope 1 emissions could include reducing ambulance idling time at emergency scenes and receiving hospitals, transitioning to higher efficiency vehicle fleets, and limiting the use of medical helicopters to only those emergency situations in which they have been shown to improve patient outcomes.

Other strategies for reducing ambulance system Scope 1 emissions would mirror those of the broader transportation sector. Conversion to bio-diesel as a vehicle fuel would reduce direct emissions, although the complete life cycle emissions of bio-fuels are not necessarily significantly less than those of fossil-based liquid fuels (Nanaki & Koroneos, 2012; Solomon, 2010; von Blottnitz & Curran, 2007). For example, in Australia low sulphur diesel emissions are only marginally greater than emissions from 'E15D diesohol' (a blend of low sulphur diesel and 15% ethanol): 925 g CO2e / km versus 862 g CO2e / km (Beer & Grant, 2007). Bio-fuels are also often associated with other detrimental environmental and land use effects (Lange, 2011; Nanaki & Koroneos, 2012; Solomon, 2010; von Blottnitz & Curran, 2007).

Another potential strategy is to transition to a more efficient ambulance and support vehicle fleet. Plug-in hybrid electric vehicles (PHEVs) are one option, but depending on the fuel source for electricity generation, they might simply shift Scope 1 greenhouse gas emissions to Scope 2 emissions. A case study from Milan, Italy, asserted that thermal power stations in that region were efficient enough to justify the introduction of electric vehicles into the private vehicle fleet, although they could dramatically increase peak electricity demand (Perujo & Ciuffo, 2010). Sioshansi, Fagiani, & Marano (2010) came to the same conclusion for PHEVs in Ohio despite that U.S. state's high concentration of coal-fired power plants, although emissions of sulphur dioxide and nitrogen oxides were substantially higher for PHEVs compared to conventional vehicles. An analysis from California also found that PHEVs—as well as battery electric vehicles (BEVs)—would produce lower complete life cycle greenhouse gas emissions than both conventional and hybrid internal combustion engines (McCarthy & Yang, 2010). To my knowledge, an assessment of the environmental impacts of PHEVs in Australia has not been reported.

Hydrogen fuel cell vehicles (FCVs) are another option for both support and transport vehicles, but again the process of hydrogen production can profoundly impact their life cycle emissions (Ozalp, Epstein, & Kogan, 2010; Pro, Hammerschlag, & Mazza, 2005). In New Zealand, Leaver & Gillingham (2010) estimated that FCVs, along with BEVs, would be the best alternative vehicle technologies for reducing greenhouse gas emissions. In London, FCV taxis have lower complete life cycle energy consumption and emissions than diesel and BEV taxis (Baptista et al., 2011). On the contrary, in the U.S. state of California, McCarthy & Yang (2010) predicted FCVs would produce more greenhouse gas emissions than conventional or hybrid internal combustion engines given current electricity and hydrogen generation processes. A further immediate limitation on FCVs is the lack of a sufficient hydrogen distribution and refuelling infrastructure (Vergragt & Brown, 2007).

Reducing emissions from electricity consumption is another way in which ambulance services could reduce their environmental impact. In this analysis, electricity consumption accounted on average for 22% of total ambulance system emissions. In contrast to the data for Scope 1 emissions, using the inventory based determinations of electricity-related emissions reduced their contribution to the total carbon footprint of ambulance systems. This makes sense: while ambulance systems must maintain some administrative office space and facilities for housing ambulances and staff, they are primarily mobile services. Even the most optimistic estimate in this analysis, however, would put electricity-related emissions at 7% of total emissions, which would still make first order electricity consumption a leading structural path for ambulance service emissions.

Conservation efforts aimed at reducing electricity consumption could directly reduce the Scope 2 emissions of ambulance services, but advocating for ‘green’ electricity generation could have an even more profound indirect impact. All of the estimates in this analysis indicate that upstream Scope 3 emissions are the largest contributor to ambulance system emissions. Reducing the emissions intensity of electricity production could reduce not only the electricity-related Scope 2 emissions of ambulance services, but also the upstream Scope 3 emissions associated with electricity consumption in the supply chain.

Implementing environmentally friendly purchasing practices would further reduce ambulance system life cycle emissions. In this analysis, Scope 3 emissions represent nearly 60% of ambulance services’ complete life cycle emissions. This is consistent with previous data showing that indirect emissions constitute the majority of emissions arising from service sectors and service industries (Larsen & Hertwich, 2011; Nansai et al., 2009; Suh, 2006).

The leading structural paths in the Hs, Os and Gv sectors provide some insights into the products and services that ambulance services might target in those efforts. In the absence of a more detailed analysis of ambulance system purchases, it should not be presumed that the leading structural paths for ambulance services more closely resemble those of the Hs or Gv sectors simply because they seem more intuitive than those of the Os sector. Ambulance services should consider the potential benefits of reducing their consumption of, and pursuing environmentally friendly purchasing practices for, products in all of these paths. One aspect of complete life cycle emissions unique to transport systems is the end-of-life management of vehicles (Manomaivibool, 2008).

While the greenhouse gas emissions and environmental impacts of decommissioning ambulances and other vehicles might technically accrue to the manufacturers of those vehicles, ambulance systems should none-the-less pursue and promote environmentally friendly vehicle disposal.

5.7 Limitations

Admittedly, these structural paths might not represent the actual leading structural paths for ambulance services. This study did not incorporate an inventory of ambulance service purchases and, as the Scope 1 and Scope 2 data demonstrate, the aggregate TBL multipliers and structural paths for the Hs, Os, and Gv sectors might not accurately reflect the true environmental impact of Australian ambulance systems. This is a common limitation of top-down estimates of carbon footprints and structural path analyses using aggregate sectoral input-output based multipliers (Baboulet & Lenzen, 2010; Lenzen, Pade, & Munksgaard, 2004; Su, Huang, Ang, & Zhou, 2010). This analysis further highlights how the problem might be even more pronounced for activities that organisationally fit within one economic sector, but that are operationally more similar to activities in other economic sectors.

Ideally, estimating the complete life cycle emissions of Australian ambulance services would incorporate not only an inventory of their Scope 1 and Scope 2 energy consumption, but also an inventory of their purchases from which more specific input-output based estimates of Scope 3 emissions could be made. Unfortunately, that was not logistically possible for this analysis. Even if it had been possible, the study would still be limited in that the input-output tables used to construct the TBL multipliers were from 1994-1995 (Foran, Lenzen, & Dey, 2005). Thus this analysis, and any analysis using those multipliers, assumes that production processes and inter-sectoral transactions in the Australian economy have not changed substantially in the last 15 years. This too, is a common shortcoming of input-output based analyses (Foran, Lenzen, & Dey, 2005; Lenzen 2002; Su, Huang, Ang, & Zhou, 2010). These are none-the-less the most recent TBL multipliers publicly available for the Australian economy.

For both these reasons, and consistent with the ISO recommendations for life cycle analysis, these data are more useful as a starting point for tracking ambulance service emissions—and changes in those emissions—over time, rather than as an accurate point estimate of ambulance service emissions (Finkbeiner, Inaba, Tan, Christiansen, & Kluppel, 2006). In that context, any information bias resulting from the limitations of the aggregate input-output multipliers would be a non-differential information bias, and thus a bias towards the null hypothesis (of no change) when comparing year-over-year greenhouse gas emissions.

Another limitation of this analysis is that it essentially uses ‘Scope 2’ emissions and ‘electricity-related’ emissions synonymously. This is not technically correct: the direct emissions of other purchased services, most notably travel on commercial airlines, are also considered Scope 2 emissions. In the case of ambulance services, these additional Scope 2 emissions are poorly tracked (Blanchard & Brown, 2011; see also Chapter 4) but they should be relatively small. Also, in this analysis, those emissions are still represented in the calculations of indirect and Scope 3 emissions; that is, they might be misclassified, but they are not omitted.

Finally, this study uses aggregate expenditure data for Australian EMS systems, and does not differentiate between ground and air ambulance activities. As demonstrated in Chapter 4, the direct emissions associated with the consumption of aviation fuels for air ambulance activities are substantially higher than those from ground ambulances. The results of this study must be considered in the context of both ground and air ambulance activities, and should not be misinterpreted as being specific to ground ambulance operations.

5.8 Conclusion

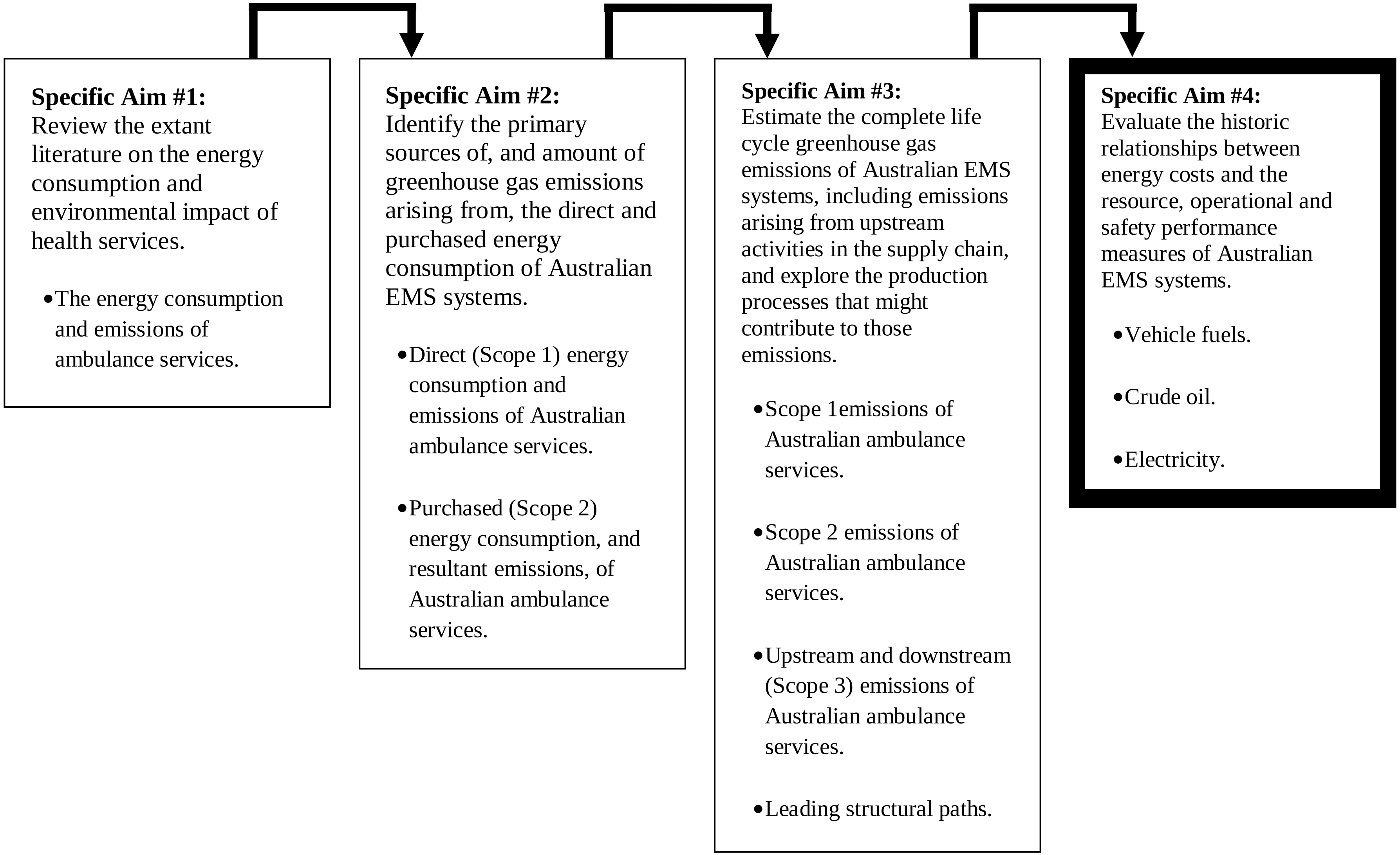
This analysis used the previous inventory of Scope 1 and Scope 2 emissions from Australian ambulance services, along with publicly available expenditure data and input-output based TBL multipliers, to estimate the complete life cycle emissions of Australian ambulance services. Complete life cycle emissions from Australian ambulance services are estimated at between 216,000 and 547,000 t CO_2e annually. Ambulance services are responsible for between 1.8% and 4.4% of total Australian health sector emissions, and can play an important role in reducing health sector emissions. Scope 3 emissions are responsible for the majority of ambulance service emissions, but direct emissions from vehicle fuels including diesel, petrol and aviation fuel represent approximately 20% (and perhaps as much as 37%) of total ambulance system emissions and are an obvious target for reducing the environmental impact of ambulance systems.

While this chapter and the previous chapter have focused on the environmental burden associated ambulance systems, there are other reasons to manage energy consumption. The next chapter explores one of these reasons: the impact of energy costs on ambulance systems.

Chapter 6: Energy Costs and Australian EMS Systems

Chapter 4 inventoried the Scope 1 and Scope 2 greenhouse gas emissions of Australian ambulance services, and Chapter 5 made an estimate of their complete life cycle emissions. Environmental concerns, however, are not the only reason to manage energy consumption. This chapter explores the potential importance of energy scarcity and rising energy costs for Australian ambulance services (Figure 6.1).

This chapter has been adapted into a manuscript: Brown, L.H., Chaiechi, T., Buettner, P.G., Canyon, D.V., Crawford, J.M., Judd, J. (Under Review). How do energy prices impact ambulance services? Evidence from Australia.



Specific Aim #1:
Review the extant literature on the energy consumption and environmental impact of health services.

- The energy consumption and emissions of ambulance services.

Specific Aim #2:
Identify the primary sources of, and amount of greenhouse gas emissions arising from, the direct and purchased energy consumption of Australian EMS systems.

- Direct (Scope 1) energy consumption and emissions of Australian ambulance services.
- Purchased (Scope 2) energy consumption, and resultant emissions, of Australian ambulance services.

Specific Aim #3:
Estimate the complete life cycle greenhouse gas emissions of Australian EMS systems, including emissions arising from upstream activities in the supply chain, and explore the production processes that might contribute to those emissions.

- Scope 1emissions of Australian ambulance services.
- Scope 2 emissions of Australian ambulance services.
- Upstream and downstream (Scope 3) emissions of Australian ambulance services.
- Leading structural paths.

Specific Aim #4:
Evaluate the historic relationships between energy costs and the resource, operational and safety performance measures of Australian EMS systems.

- Vehicle fuels.
- Crude oil.
- Electricity.

Figure 6.1: Progress through the thesis: Specific Aim #4.

6.1 Abstract

Concerns about the impacts of energy scarcity and rising energy prices on health services are increasing, and there are multiple reports in the lay media specifically warning of the adverse effects of fuel price hikes on ambulance services. This study empirically evaluates the impact of historical energy price fluctuations on Australian ambulance services. A panel data approach is used to investigate the effect of energy prices on ambulance system resource, operational and safety performance measures. The data reveal an inverse relationship between fuel prices and ambulance service resources, and a one-year lagged association between increases in fuel prices and longer response times. There is also a positive association between electricity prices and workplace injury compensation claims.

6.2 Introduction

The potential adverse impacts of rising energy prices on health services are the subject of much opinion, but little empirical evaluation. Three decades ago, noting that health facilities are dependent on energy, Bailey (1980) raised concerns about energy scarcity and energy costs in the context of the U.S. dependence on imported oil. More recently, several authors have warned of the threats posed to all health systems by global peak oil. They argue that energy is a critical input for health services (Frumkin, Hess, and Vindigni, 2007; 2009; Hanlon & McCartney, 2008; Hess, Bednarz, Bae, & Pierce, 2011; Schwartz, Parker, Hess, & Frumkin, 2011; Wilkinson, 2008; Winch & Stepnitz, 2011) and that there are several pathways through which energy scarcity and energy costs could affect health services, including: the cost and availability of medical supplies and equipment; the cost and availability of health-related transport; the cost of lighting, heating and air conditioning health facilities; impacts on food security leading to increased demand on health services; and economic impacts that disrupt funding for health services (Clark & Kline, 1981; Frumkin, Hess, & Vindigni, 2009; Winch & Stepnitz, 2011). These concerns are shared by the general public. In a 2009-2010 survey of U.S. adults, 48% said they anticipated a tripling of oil prices over the next five years, and 44% said those price increases would be harmful to health (Nisbet, Maibach, & Leiserowitz, 2011). There is some, albeit minimal, empirical basis for these concerns. In a time series analysis of U.S. petroleum and health care prices between 1973 and 2008, Hess et al. (2011) found a 1% increase in oil price inflation was associated with a 0.03% increase in medical care prices after an eight month lag. This price elevation persisted for 20 months, although the effect was much stronger in the 1970s than in recent years.

Ambulance services are an integral component of the health care system (Delbridge et al., 1998). Recent reports in the lay media have anecdotally described the adverse effects of rising fuel costs on the operating budgets of these services (Anonymous, 2011; Fallon, 2011; Harlin, 2009; Odell, 2011; Penner, 2008), but the extent of those impacts and how they manifest have not been empirically studied. Ambulance services are complex systems involving vehicles, equipment, buildings, communication systems and personnel (Lerner, Nichol, Spaite, Garrison, & Maio, 2007), and increasing energy costs could conceivably impact any or all of these system components. This study evaluates the impact of historical energy price fluctuations on Australian ambulance services, using a panel data approach to test the null hypothesis that ambulance service resource, operational and safety performance characteristics are not associated with energy prices.

6.3 Methodology

6.3.1 Setting

In Australia, responsibility for ambulance services rests with state and territory governments. In NSW, SA, and TAS ambulance services are provided by the Department of Health. In QLD and the ACT ambulance services are provided by the departments responsible for emergency services. St. John's Ambulance Service, an independent not-for-profit organisation, is contracted to provide services in NT and WA. In VIC, ambulance services are now organised within the Department of Health, but prior to 2008 they were provided by two independent statutory authorities: the Metropolitan Ambulance Service (MAS) serving the greater Melbourne area, and Rural Ambulance Victoria (RAV) serving the remainder of the state. In the 2009-2010 financial year, Australian ambulance services performed slightly more than 3.5 million emergency and non-emergency responses (Council of Ambulance Authorities, 2010).

6.3.2 Design

This was a retrospective study using a panel data approach to evaluate the historical relationships between energy prices and resource allocation, as well as operational and safety performance measures, in Australian ambulance agencies.

6.3.3 Data Sources

6.3.3(a) Ambulance Service Data

Data on the resource, operational and safety characteristics of the ambulance services in Australia's six states were obtained from publicly available annual reports published online at each agency's website, or its parent agency's (e.g., Department of Health) website. While Ambulance-Victoria data for the entire state of VIC were available from the 2008-2009 financial year forward, only annual reports for MAS were available for prior years. These agencies were treated as individual systems in this analysis because of the differences in their structures and geographic service areas. Limited resource and operational performance data for the ambulance agencies serving Australia's two territories (NT and ACT) were extracted from Australia's CAA annual reports, also available online. Table 6.1 shows the administrative structure of, and the timeframes for which data were available for, each ambulance service.

Table 6.1: Administrative structure and timeframes of included data for each ambulance system.

System	Administrative Home	Beginning Year	Final Year
Australian Capital Territory	Emergency Services	2000-2001	2009-2010
Northern Territory	Independent	2001-2002	2009-2010
New South Wales	Health Department	2000-2001	2007-2008
Queensland	Emergency Services	2003-2004	2009-2010
South Australia	Health Department	2002-2003	2008-2009
Tasmania	Health Department	2002-2003	2009-2010
Victoria – MAS	Independent	2002-2003	2007-2008
Victoria – A-V	Health Department	2008-2009	2009-2010
Western Australia	Independent	2001-2002	2009-2010

MAS – Metropolitan Ambulance Service; A-V – Ambulance Victoria

The extracted annual data included: number of ambulance responses; total expenditures; labour-related expenditures; number of full time equivalent (FTE) employees; number of work-related injury compensation claims; median response time; and 90th percentile response time. When response time data were not included in the individual state ambulance agency annual reports, these indicators were instead extracted from the CAA annual reports. Lastly, CAA also conducts an annual nationwide patient satisfaction survey from which reported satisfaction with ambulance response times (on a scale of 0 to 100), beginning with the 2003-2004 financial year, was also extracted. In some cases, prior year data were reported in the first available report, allowing collection (or calculation) of data for one additional year.

From these data, nine performance measures were identified or calculated: four resource performance indicators, three operational performance indicators, and two safety performance indicators. Table 6.2 describes each performance indicator in detail.

6.3.3(b) Energy Price Data

The Australian Institute of Petroleum (AIP) reports annual average terminal gate prices (TGP) for diesel fuel and petrol in Australia's capital cities, with the exception of Canberra, ACT. TGP reflects the wholesale price of diesel or petrol with goods and services tax added. TGP data for diesel fuel for financial years 2004-2005 through 2009-2010 were obtained from the AIP website (Australian Institute of Petroleum, 2010), and the annual average TGP for diesel fuel in each capital city (as cents per L) was used as a measure of vehicle fuel prices for each state or territory. The annual average TGP for Sydney, NSW was used as a proxy measure for the cost of diesel in the ACT.

State average annual electricity prices (as dollars per megawatt hour) for financial years 2000-2001 through 2009-2010 were obtained from the Australian Energy Market Operator (AEMO) (Australian Energy Market Operator, 2010). AEMO data for TAS were limited to the 2004-2005 through 2009-2010 financial years, and the AEMO data does not include electricity price data for WA, NT, or ACT. Electricity prices for NSW were used as a proxy for electricity prices in ACT, but because of their remoteness, distinctive geography and unique economies, a proxy measure of electricity prices for NT and WA was not attempted.

Since TGP data were available for only six financial years, average annual world crude oil prices were used as an additional indirect measure of vehicle fuel costs with a longer historical record. Oil prices were obtained from the U.S. EIA’s reported world weekly average crude oil prices for financial years 2000-2001 through 2009-2010 (U.S. Energy Information Administration, 2011). Since these EIA data are reported in U.S. dollars, annual average exchange rates reported by the Australian Tax Office (Australian Tax Office, 2011) were used to convert these prices into Australian dollar prices (as dollars per barrel).

6.3.4 Analysis

6.3.4(a) Model Selection

The panel data analysis followed the approaches outlined by Markus (1979), Hsiao (1986) and Twisk (2003). Generalised Estimating Equation (GEE) modelling was used to evaluate the relationships between the energy price measures and the system performance measures while accounting for the repeated-measures nature of the performance measures. GEE modelling, which was initially proposed by Liang & Zeger (1986) and Zeger & Liang (1986), considers a two-part estimating equation that simultaneously estimates (1) the regression parameters and (2) the parameters of the second order variance distribution. Thus, in GEE the relationships between the variables in the model at different time points are analysed simultaneously (Liang and Zeger 1986; Twisk, 2003); conceptually it can be thought of as regression modelling with correction for the dependency of the serial observations (Burton, Gurrin, & Sly, 1998). GEE models generate robust and model-based standard errors, and produce consistent normal solutions even if the underlying correlation structure is incorrectly specified (Twisk, 2003; Zeger & Liang, 1986). This makes GEE well suited for both unbalanced and non-stationary panel data.

6.3.4(b) Model Specification

The model is estimated on an unbalanced data set that does not require independent observations. The analysis evaluated both the contemporaneous (that is, within the same financial year) and one-year lagged relationships between energy prices and each individual performance measure while controlling for system administrative structure, which was dichotomised as ‘health department based’ or ‘non health department based’. For modelling of contemporaneous effects, GEE was conducted specifying the correlation structure of the dependent variable and using the robust estimation of standard errors as:

$$Y_{it} = \beta_0 + \beta_1 \text{Admin}_i + \beta_2 \text{Diesel\$}_{it} + \beta_3 \text{Elect\$}_{it} + \beta_4 t + \text{CORR}_{it} + \varepsilon_{it}$$

or

$$Y_{it} = \beta_0 + \beta_1 \text{Admin}_i + \beta_2 \text{Oil\$}_t + \beta_3 \text{Elect\$}_{it} + \beta_4 t + \text{CORR}_{it} + \varepsilon_{it}$$

where Y is the performance measure for the ambulance service in state or territory *i* for year *t*; Admin_i is the administrative structure of each ambulance system; $\text{Diesel\$}_{it}$ is the average terminal gate price for diesel in each state or territory for year *t*; $\text{Oil\$}_t$ is the average world crude oil price for year *t*; $\text{Elect\$}_{it}$ is the average electricity price in each state or territory for year *t*; *t* is the year of observation, CORR is a correction term for the auto-correlated errors in the dependent variable; and ε is the error term.

Both time-lag effects and autoregression should also be considered when estimating GEE models. Time-lagged models are particularly useful when the time periods in the dataset are short. Autoregressive models are useful in the sense that they allow for the influence of previous values of dependent variables, in this case the performance measures for the ambulance services. Therefore, lagged relationships were evaluated using an auto-regressive GEE model as:

$$Y_{it} = \beta_0 + \beta_1 \text{Admin}_i + \beta_2 \text{Diesel\$}_{it-1} + \beta_3 \text{Elect\$}_{it-1} + \beta_4 Y_{it-1} + \beta_5 t + \varepsilon_{it}$$

or

$$Y_{it} = \beta_0 + \beta_1 \text{Admin}_i + \beta_2 \text{Oil\$}_{t-1} + \beta_3 \text{Elect\$}_{it-1} + \beta_4 Y_{it-1} + \beta_5 t + \varepsilon_{it}$$

where Y is the performance measure for the ambulance service in state or territory *i* for year *t*; Admin_i is the administrative structure of each ambulance system; $\text{Diesel\$}_{it-1}$ is the average terminal gate price for diesel in each state or territory for year *t-1*; $\text{Oil\$}_{t-1}$ is the average world crude oil price for year *t-1*; $\text{Elect\$}_{it-1}$ is the average electricity price in each state or territory for year *t-1*; Y_{it-1} is the prior year value of the dependent variable for each service; *t* is the year of observation, *t-1* is the prior year, and ε is the error term.

Lastly, because the inclusion of electricity price in the models eliminated NT and WA from the analyses, both the contemporaneous and lagged effects of diesel price and crude oil price on the performance indicators for those two ambulance services were modelled separately as:

$$Y_{it} = \beta_0 + \beta_1 \text{Diesel\$}_{it} + \beta_2 t + \text{CORR}_{it} + \varepsilon_{it}$$

$$Y_{it} = \beta_0 + \beta_1 \text{Oil\$}_{t} + \beta_2 t + \text{CORR}_{it} + \varepsilon_{it}$$

$$Y_{it} = \beta_0 + \beta_1 \text{Diesel}_{it-1} + \beta_2 Y_{it-1} + \beta_3 t + \varepsilon_{it}$$

$$Y_{it} = \beta_0 + \beta_1 \text{Oil\$}_{t-1} + \beta_2 Y_{it-1} + \beta_3 t + \varepsilon_{it}$$

with the variables defined as above.

6.3.4(c) Specification of the Correlation Structure

To address the dependence of the variables in the analyses of the contemporaneous relationships, the correlation structure of each dependent variable was determined by first creating a separate table showing the correlation between the values of that variable for each year included in the study. These tables were then evaluated as recommended by Twisk (2003) to determine the most appropriate correlation structure; the simplest correlation structure that could reasonably be interpreted as fitting the data and for which the GEE modelling could achieve convergence was used. Also as recommended by Twisk (2003), all of the autoregressive GEE modelling in the analyses of the lagged relationships was conducted using an independent correlation structure.

6.3.4(d) Model Fit and Statistical Significance

Model fit was evaluated by calculating the explained variance in each model, as:

$$\text{Explained variance} = 1 - \left(\frac{\text{variance of the model}}{\text{variance of the dependent variable}} \right)$$

For all analyses, an alpha value of 0.05 was used to establish statistical significance.

6.4 Ethical Review

This study was approved by the HREC at James Cook University (HREC #3982, Appendix 1) with the understanding that the results would be aggregated and reported in a manner such that individual system performance could not be determined.

6.5 Results

6.5.1 General Results

During the years included in this study, Australian ambulance systems performed more than 20 million ambulance responses, with annual median response times ranging between 7.2 and 11.0 minutes at an average (± standard deviation) expense of \$542 ± \$126 per response. The aggregate measures of all the performance indicators are shown in Table 6.2.

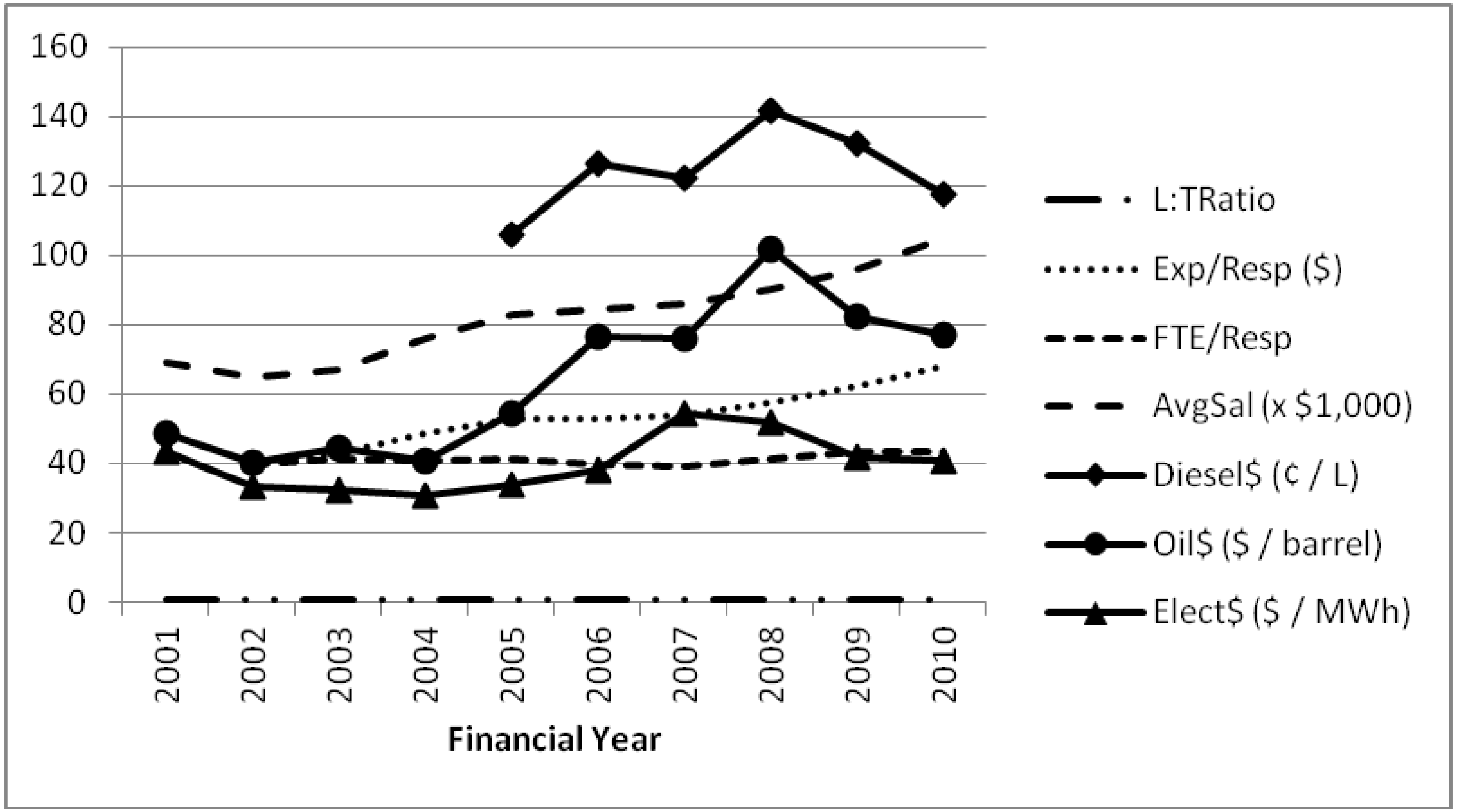
None of these measures were reported for all ambulance systems for all years, except for 90th percentile response time; Table 6.2 also shows the number of system-years for which performance indicator data were available. Safety-related performance measures were the most under-reported performance measure, available for only four systems for a total of 20 system-years.

Figures 6.2 through 6.4 show the relationships between energy prices and the aggregate resource, operational and safety performance measures over the years included in the study. While similar movements in the three energy price measures are apparent, there are no obvious associated trends in the resource, operational or safety performance indicators.

Table 6.2: Ambulance service performance indicators extracted or calculated from the annual reports, total system-years of observations, and aggregate results for the entire study period.

Performance Indicator	Calculation	N System-Years	Mean (± Standard Deviation)
Resource Indicators			
Expenditures per Response ($)	Total Expenditures / Total Responses	61	542.04 ± 125.99
Labour to Total Expenditure Ratio	Labour Expenditure / Total Expenditures	64	0.65 ± 0.05
FTE per 10,000 Responses	FTE / Total Responses × 10,000	60	40.95 ± 5.32
Average Salary ($ 000)	Labour Expenditures / FTE	60	85.57 ± 16.53
Operational Indicators			
Median Response Time (min)	As Reported	70	9.26 ± 0.90
90th Percentile Response Time (min)	As Reported	80	17.56 ± 2.92
Patient Satisfaction with Response Time	As Reported	46	93.02 ± 4.00
Safety Indicators			
Compensation Claims per 10,000 Responses	Compensation Claims / Total Responses × 10,000	20	6.80 ± 2.93
Compensation Claims per 100 FTE	Compensation Claims / FTE × 100	20	17.75 ± 5.98

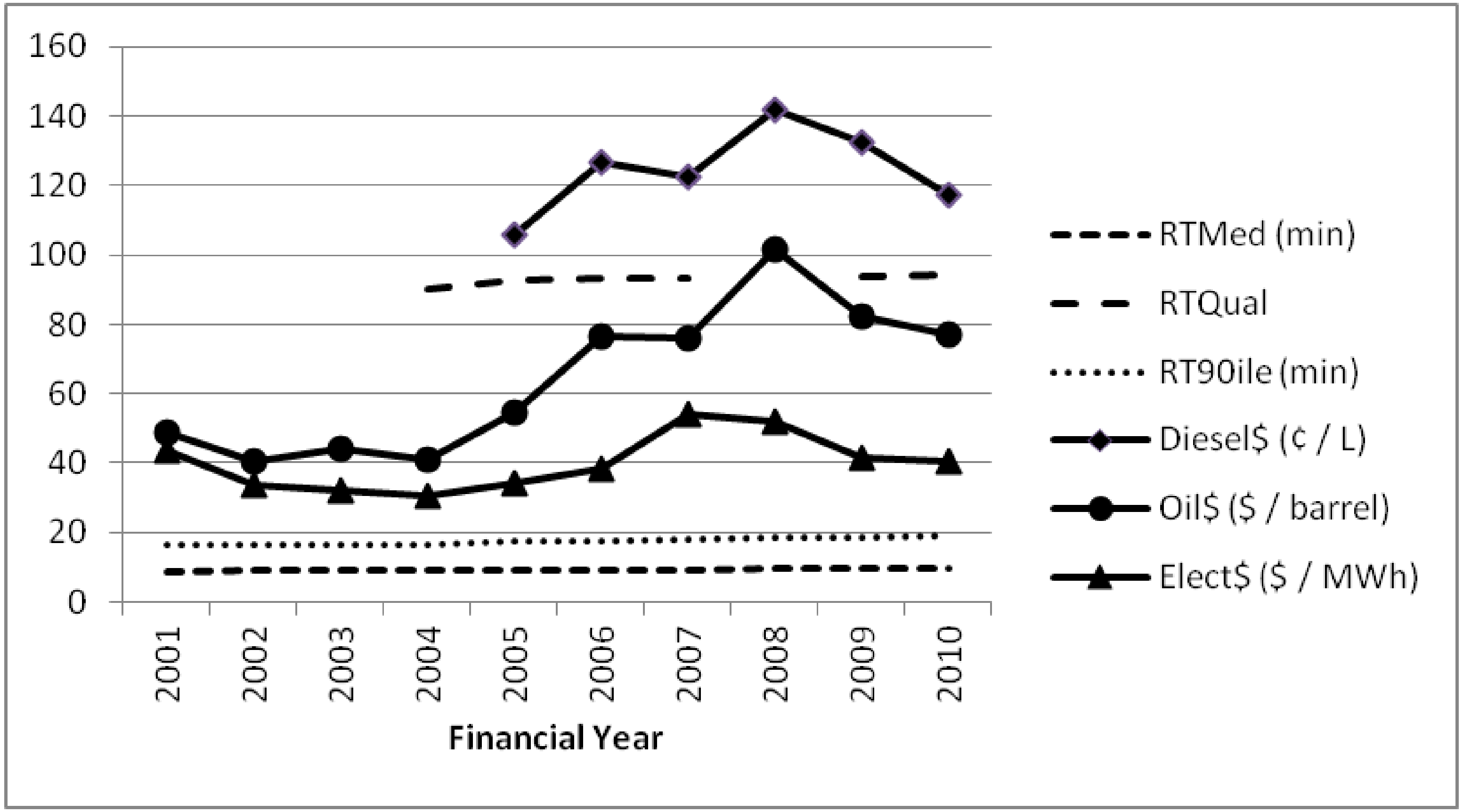
$ - Australian dollars; $ 000 – thousand Australian dollars; FTE – full time equivalent employees; min – minutes



Note: The scale of the Y axis varies for each variable, as indicated in the figure legend.

L:TRatio – labour-to-total expenditure ratio; Exp/Resp – expenditures per response ($); FTE/Resp – full time equivalent employees per 10,000 responses; AvgSal – average salary (x $1,000); Diesel$ – diesel price (cents/litre); Oil$ – oil price ($/barrel); Elect$ – electricity price ($/megawatt hour).

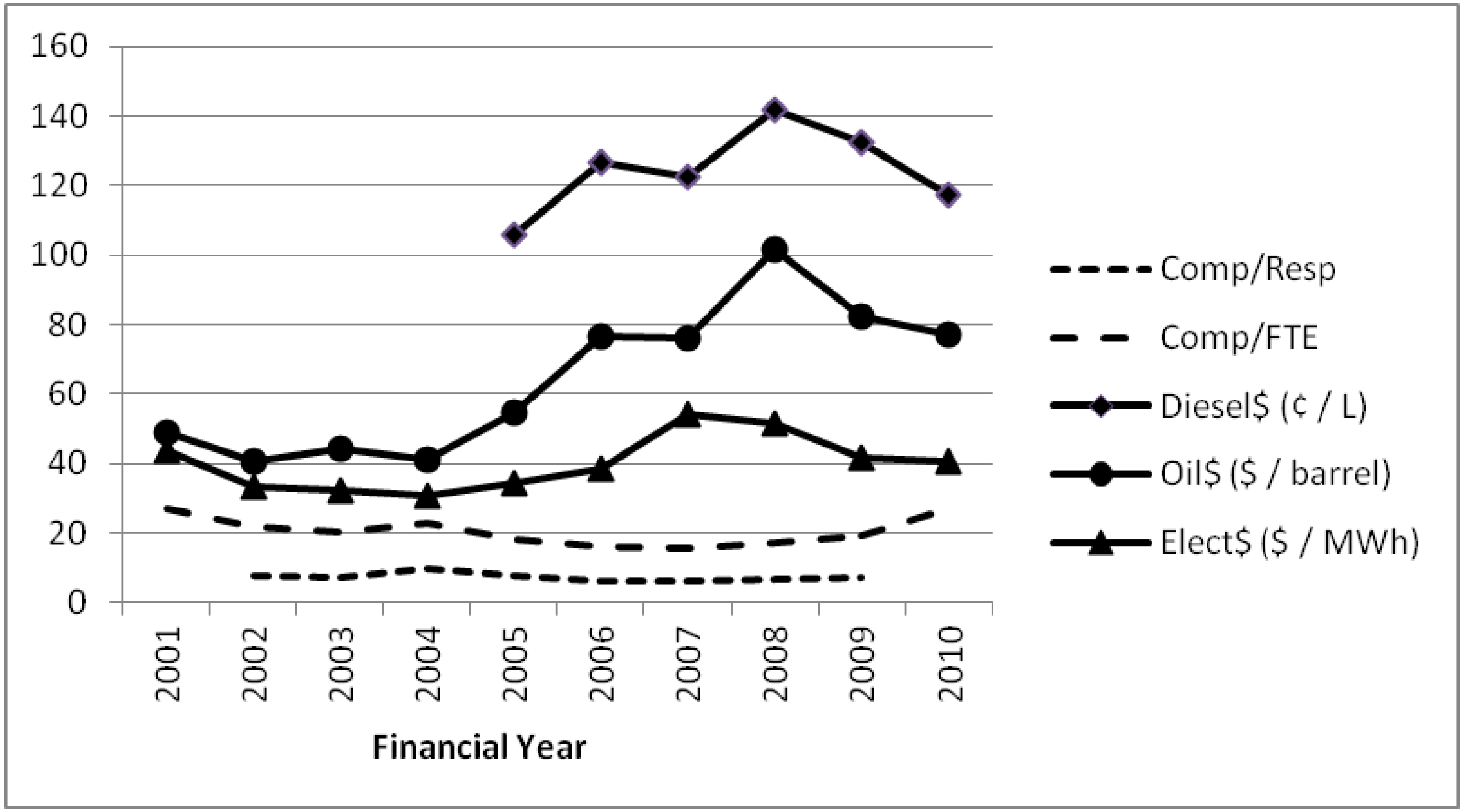
Figure 6.2: Energy prices and resource performance indicators for Australian ambulance systems, 2001 - 2010.



Note: The scale of the Y axis varies for each variable, as indicated in the figure legend.

RTMed – median response time (minutes); RTQual – response time quality score (0 to 100); RT90ile – 90th percentile response time (minutes); Diesel$ – diesel price (cents/litre); Oil$ – oil price ($/barrel); Elect$ – electricity price ($/megawatt hour).

Figure 6.3: Energy prices and operational performance indicators for Australian ambulance systems, 2001 - 2010.



Note: The scale of the Y axis varies for each variable, as indicated in the figure legend.

Comp/Resp – injury compensation claims per 10,000 responses; Comp/FTE – injury compensation claims per 100 full time equivalent employee; Diesel$ – diesel price (cents/litre); Oil$ – oil price ($/barrel); Elect$ – electricity price ($/megawatt hour).

Figure 6.4: Energy prices and safety performance indicators for Australian ambulance systems, 2001 - 2010.

6.5.2 Contemporaneous Effects

Table 6.3 shows the results of the GEE models evaluating contemporaneous associations between performance indicators, time, system characteristics and energy prices in those systems for which electricity data were available. Expenditures per response increased over time, as did 90th percentile response times, while injury compensation claims decreased over time. Non health-based systems had shorter response times and fewer injury compensation claims than health-based systems.

6.5.2(a) Contemporaneous Effects of Energy Prices

Increasing diesel price was associated with decreasing ambulance service resources: the coefficient [standard error] for expenditures per response was -2.740 [1.171]; for FTE per 10,000 responses it was -0.074 [0.020]. When using oil price instead of diesel price in the model, the same downward effect of energy prices on resource indicators was observed for both expenditures per response (-2.490 [0.806]) and FTE per 10,000 responses (-0.057 [0.021]).

The only statistically significant contemporaneous association between electricity prices and the resource or operational performance indicators was a positive association between electricity price and average salary (0.292 [0.147]) when electricity price was modeled with diesel price. Among the safety indicators, however, increasing electricity prices were associated with increased injury compensation claims per 100 FTE, whether electricity price was modeled with diesel price (0.201 [0.072]) or with oil price (0.151 [0.069]) (Table 6.3).

Table 6.3: Contemporaneous associations between energy prices and ambulance system performance indicators.

(Model)	Dependent Variables - coefficient [standard error]								
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual	Comp/Resp	Comp/FTE
(Diesel$ & Elect$)									
Non Health-Based	57.663	-0.019	0.356	4.043	-1.018*	-2.985*	-1.291*	-4.375*	-9.125*
	[76.901]	[0.037]	[4.479]	[4.829]	[0.465]	[1.259]	[0.730]	[1.060]	[0.662]
Year	39.500*	0.003	0.321	5.777*	0.197	0.297*	0.080	-0.524*	-2.339*
	[10.061]	[0.006]	[0.348]	[1.854]	[0.106]	[0.137]	[0.097]	[0.079]	[0.154]
Diesel$	-2.740*	-0.001	-0.074*	-0.355	0.004	0.021	0.050	-0.007	0.060
	[1.171]	[0.0004]	[0.020]	[0.250]	[0.004]	[0.013]	[0.040]	[0.296]	[0.074]
Elect$	0.676	-0.001	-0.050	0.292*	-0.005	-0.027	-0.013	0.053	0.201*
	[0.733]	[0.0004]	[0.040]	[0.147]	[0.009]	[0.020]	[0.022]	[0.036]	[0.072]
Explained Variance	41.0%	6.4%	12.9%	48.5%	60.7%	58.4%	87.3%	70.3%	82.7%

* $p < 0.05$; AvgSal – average salary (x $1,000); Comp/FTE – injury compensation claims per 100 full time equivalent employees; Comp/Resp – injury compensation claims per 10,000 responses; Diesel$ – diesel price (¢/L); Elect$ – electricity price ($/megawatt hour); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100)

Table 6.3 (continued): Contemporaneous associations between energy prices and ambulance system performance indicators.

(Model)	Dependent Variables - coefficient [standard error]								
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual	Comp/Resp	Comp/FTE
(Oil$ & Elect$)									
Non Health-Based	55.634	-0.178	0.288	4.426	-1.212*	-3.201*	-2.594*	-4.265*	-8.596*
	[67.779]	[0.031]	[4.545]	[4.292]	[0.449]	[1.373]	[0.972]	[1.217]	[1.253]
Year	53.036*	0.001	0.586*	6.162*	0.139	0.149*	-0.419	-0.385*	-1.855*
	[11.745]	[0.005]	[0.173]	[2.005]	[0.084]	[0.054]	[0.342]	[0.147]	[0.269]
Oil$	-2.490*	-0.0003	-0.057*	-0.293	0.003	0.020	0.135	-0.011	0.036
	[0.806]	[0.0003]	[0.021]	[0.234]	[0.003]	[0.012]	[0.112]	[0.026]	[0.063]
Elect$	0.766	-0.001	-0.052	0.281	-0.004	-0.017	0.000	0.044	0.151*
	[0.778]	[0.0003]	[0.033]	[0.160]	[0.008]	[0.020]	[0.028]	[0.035]	[0.069]
Explained Variance	56.3%	12.7%	14.1%	53.9%	60.8%	51.9%	32.6%	61.2%	78.3%

* $p < 0.05$; AvgSal – average salary (x $1,000); Comp/FTE – injury compensation claims per 100 full time equivalent employees; Comp/Resp – injury compensation claims per 10,000 responses; Diesel$ – diesel price (¢/L); Elect$ – electricity price ($/megawatt hour); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; Oil$ – oil price ($/barrel); RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100)

6.5.3 Lagged Effects

Table 6.4 shows the results of the GEE models evaluating one-year lagged associations between performance indicators, time, system characteristics and energy prices in those systems for which electricity data were available. As expected, most of the performance indicators were strongly influenced by their lagged (prior year) values. When modelling lagged diesel price and electricity price, expenditures per response and average salary trended upward year over year, median response times trended downward, and non health-based systems had lower response time quality scores. These associations, however, did not persist when the model included oil price instead of diesel price.

6.5.3(a) Lagged Effects of Energy Prices

Increasing prior year diesel price was associated with an increase in median response time (0.026 [0.008]). The same positive association between fuel prices and median response time was seen when using lagged oil price instead of diesel price in the model (0.011[0.005]). There were no statistically significant associations between lagged electricity prices and any of the resource, operational or safety performance indicators.

Table 6.4: Lagged associations between energy prices and ambulance system performance indicators.

(Model)	Dependent Variables - coefficient [standard error]								
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual	Comp/Resp	Comp/FTE
(Lagged Diesel$ & Elect$)									
Non Health-Based	-14.382	-0.003	0.027	-0.398	0.221	0.426	-2.578*	-1.287	-6.506
	[31.896]	[0.011]	[0.796]	[5.450]	[0.171]	[0.358]	[1.251]	[1.382]	[4.116]
Year	42.307*	0.011	0.619	6.696*	-0.167*	-0.126	0.277	0.035	-1.655
	[16.798]	[0.006]	[0.449]	[2.861]	[0.070]	[0.151]	[0.398]	[0.635]	[2.002]
1 Lag Diesel$	-0.861	-0.003	0.043	-0.267	0.026*	0.004	-0.044	-0.004	0.034
	[1.930]	[0.001]	[0.052]	[0.332]	[0.008]	[0.019]	[0.072]	[0.049]	[0.118]
1 Lag Elect$	-0.481	0.001	0.020	0.098	0.003	0.026	-0.092	0.007	0.105
	[1.469]	[0.001]	[0.039]	[0.713]	[0.006]	[0.014]	[0.072]	[0.042]	[0.123]
1 Lag Dependent Variable	0.832*	0.915*	0.819*	0.480	0.980*	1.002*	-0.272	0.616*	0.178
	[0.128]	[0.102]	[0.064]	[0.265]	[0.097]	[0.068]	[0.353]	[0.231]	[0.400]
Explained Variance	75.9%	75.5%	90.9%	48.1%	91.1%	94.3%	85.4%	86.0%	87.2%

$p < 0.05$; AvgSal – average salary (x $1,000); Comp/FTE – injury compensation claims per 100 full time equivalent employees; Comp/Resp – injury compensation claims per 10,000 responses; Diesel$ – diesel price (¢/L); Elect$ – electricity price ($/megawatt hour); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100); 1 Lag – prior year

Table 6.4 (continued): Lagged associations between energy prices and ambulance system performance indicators.

(Model)	Dependent Variables - coefficient [standard error]								
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual	Comp/Resp	Comp/FTE
(Lagged Oil$ & Elect)									
Non Health-Based	11.968	-0.005	0.653	3.248	-0.030	-0.009	-1.844	-1.175	-3.598
	[28.858]	[0.010]	[0.824]	[4.399]	[0.141]	[0.234]	[1.025]	[0.909]	[2.269]
Year	22.757	0.004	0.219	3.595	-0.045	0.092	0.255	0.309	0.366
	[15.855]	[0.005]	[0.483]	[2.142]	[0.046]	[0.082]	[0.563]	[0.364]	[0.634]
1 Lag Oil$	-1.336	-0.0004	-0.025	-0.147	0.011*	-0.009	-0.015	-0.034	-0.085
	[1.577]	[0.001]	[0.050]	[0.232]	[0.005]	[0.011]	[0.060]	[0.034]	[0.066]
1 Lag Elect$	0.451	0.0004	0.048	0.201	-0.001	0.018	-0.056	0.002	0.031
	[1.489]	[0.001]	[0.045]	[0.242]	[0.006]	[0.012]	[0.068]	[0.032]	[0.077]
1 Lag Dependent Variable	0.879*	0.827*	0.882*	0.446*	0.883*	0.932*	0.130	0.684*	0.492*
	[0.127]	[0.103]	[0.065]	[0.218]	[0.073]	[0.044]	[0.09]	[0.136]	[0.198]
Explained Variance	74.7%	70.0%	87.1%	54.0%	91.7%	95.2%	81.7%	88.1%	88.3%

* $p < 0.05$; AvgSal – average salary (x $1,000); Comp/FTE – injury compensation claims per 100 full time equivalent employees; Comp/Resp – injury compensation claims per 10,000 responses; Diesel$ – diesel price (¢/L); Elect$ – electricity price ($/megawatt hour); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; Oil$ – oil price ($/barrel); RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100); 1 Lag – prior year

6.5.4 Results for Systems without Electricity Data

Table 6.5 shows the results for the GEE modelling limited to the WA and NT data, for which electricity price data were not available. The labour-to-total expenditure ratio increased over time in all of the models. The 90th percentile response time increased over time in the contemporaneous models of both diesel price and oil price. Median response time increased over time in the lagged models, while response time quality decreased over time. As in the analyses above, expenditures per response, labour-to-total expenditure ratio, 90th percentile response time and response time quality were all significantly associated with their prior year values in the lagged analyses.

6.5.4(a) Effects of Diesel and Oil Price in Systems without Electricity Data

The only contemporaneous effect of diesel or oil price in the systems without electricity data was a positive association between FTE per 10,000 responses and both diesel (0.163 [0.072]) and oil (0.072 [0.027]) prices. There was a downward effect of increasing lagged diesel price on both expenditures per response (-4.143 [1.449]) and labour-to-total expenditure ratio (-0.002 [0.0004]); the effect of lagged oil price on resource indicators was limited to the labour-to-total expenditure ratio (-0.001 [0.0004]). There was also an association between response time quality score and both lagged diesel price (0.703 [0.153]) and lagged oil price (0.410 [0.129]).

Table 6.5: Associations between energy prices and ambulance system performance indicators (WA and NT only).

(Model)	Dependent Variables - coefficient [standard error]						
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual
(Diesel$)							
Year	14.228	0.015*	0.315	3.625	0.136	0.438*	0.677
	[11.775]	[0.003]	[1.145]	[4.410]	[0.082]	[0.094]	[0.581]
Diesel$	1.523	-0.0001	0.163*	-0.189	-0.001	-0.010	-0.037
	[1.355]	[0.0001]	[0.072]	[0.114]	[0.005]	[0.009]	[0.108]
Explained Variance	36.1%	30.2%	14.2%	50.5%	20.5%	6.5%	10.6%
(Oil$)							
Year	14.598	0.010*	-0.260	4.252	0.061	0.261*	0.823
	[12.576]	[0.001]	[0.419]	[3.054]	[0.052]	[0.093]	[0.925]
Oil$	0.937	0.0001	0.072*	-0.029	0.002	0.046	-0.051
	[0.854]	[0.0001]	[0.027]	[0.204]	[0.001]	[0.051]	[0.102]
Explained Variance	51.7%	18.2%	13.6%	62.7%	27.3%	34.0%	9.8%

* $p < 0.05$; AvgSal – average salary (x $1,000); Diesel$ – diesel price (¢/L); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; Oil$ – oil price ($/barrel); RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100);1 Lag – prior year

Table 6.5 (continued): Associations between energy prices and ambulance system performance indicators (WA and NT only).

Model	Dependent Variables - coefficient [standard error]						
Independent Variable	Exp/Resp	L:TRatio	FTE/Resp	AvgSal	RTMed	RT90ile	RTQual
(Lagged Diesel$)							
Year	21.777	0.019*	0.367	4.933	0.317*	1.111	-3.929*
	[12.399]	[0.003]	[1.268]	[3.416]	[0.131]	[0.643]	[0.937]
1 Lag Diesel$	-4.143*	-0.002*	-0.071	-0.444	-0.014	-0.117	0.703*
	[1.449]	[0.0004]	[0.163]	[0.400]	[0.016]	[0.080]	[0.153]
1 Lag Dependent Variable	0.871*	1.023*	0.294	0.493	-0.226	0.900*	2.476*
	[0.174]	[0.066]	[0.309]	[0.304]	[0.284]	[0.199]	[0.427]
Explained Variance	84.2%	97.3%	2.8%	56.3%	31.6%	70.1%	85.1%
(Lagged Oil$)							
Year	13.238	0.014*	-0.571	4.885	0.145*	0.917*	-3.495*
	[13.554]	[0.004]	[1.029]	[2.529]	[0.073]	[0.403]	[1.168]
1 Lag Oil$	-1.317	-0.001*	0.075	-0.284	-0.004	-0.085	0.410*
	[1.376]	[0.0004]	[0.108]	[0.246]	[0.009]	[0.051]	[0.129]
1 Lag Dependent Variable	0.783*	0.942*	0.071	0.454	-0.114	0.683*	1.738*
	[0.207]	[0.067]	[0.248]	[0.241]	[0.216]	[0.202]	[0.385]
Explained Variance	72.2%	94.5%	4.7%	67.7%	45.8%	57.3%	78.2%

* $p < 0.05$; AvgSal – average salary (x $1,000); Diesel$ – diesel price (¢/L); Exp/Resp – expenditures per response ($);FTE/Resp – full time equivalent employees per 10,000 responses; L:TRatio – labour-to-total expenditure ratio; Oil$ – oil price ($/barrel); RT90ile – 90th percentile response time (minutes); RTMed – median response time (minutes); RTQual – response time quality score (0 to 100);1 Lag – prior year

6.6 Discussion

This study establishes, for the first time, that rising energy prices do impact Australian ambulance services' resource, operational and safety performance measures. Table 6.6 translates the coefficients for the main findings of this study into practical terms, demonstrating that energy costs are more than simply a financial concern for ambulance services: they have distinct resource, performance and safety implications that potentially affect both patients and personnel.

Table 6.6: Practical interpretation of the main findings.

Increase in Energy Cost	Approximate Change in Performance Measure	Timing of Effect
20¢ / L ↑ Diesel$	↓ $55 expenditure / response	contemporaneous
	↓ 1.5 FTE / 10,000 responses	contemporaneous
	30 second ↑ median response time	1 year lag
$20 / barrel ↑ Oil$	↓ $50 expenditure / response	contemporaneous
	↓ 1 FTE / 10,000 responses	contemporaneous
	13 second ↑ median response time	1 year lag
2¢ / kWh ↑ Elect$	↑ 3 - 4 injury claims / 100 FTE	contemporaneous

Diesel$ - diesel price; Elect$ - electricity price; FTE – full time equivalent employee; kWh – kilowatt hour; L – litre; Oil$ - oil price

The inverse relationship between vehicle fuel prices and expenditures per response is counter-intuitive since rising energy costs would be expected to manifest as increased total costs. This finding might be due to the positioning of Australian ambulance services within broader state- and territory-based government services. As energy costs rise, state and territory governments are faced with difficult decisions about how to apportion limited resources, and some services inevitably undergo reductions in their allocations. These data suggest ambulance service budgets suffer in times of rising fuel prices—or, conversely, that ambulance service budgets benefit when fuel prices drop.

In this study, increases in diesel and oil prices manifested not only as reduced expenditures per response, but also as a reduction in FTE per 10,000 responses. These data are contrary to previous data from industry, where labour is generally a substitute for energy (Arnberg & Bjorner, 2007; Nguyen & Streitwieser, 1999; Woodland, 1993). While the explained variance in these models was low (13-14%) the effect sizes were quite meaningful. For instance, an ambulance system responding to 100,000 calls per year could lose as many as 15 FTE if the TGP for diesel increased just 20 cents per L. Certainly ambulance systems would be unlikely to electively institute layoffs in response to energy price rises in the short term, but they might be prevented from filling staff vacancies that result from natural attrition or from adding additional employees despite increasing response volumes.

Increasing electricity prices were associated with increased injury compensation claims per 100 FTE, whether electricity price was modelled with diesel price or with oil price. Although safety performance indicators were only available for four systems and a small subset of the system-years represented in this study, the models for injury compensation claims per 100 FTE were strong, with explained variances of around 80%. To my knowledge, this is the first evaluation to report a link between rising energy prices and increasing workplace injury claims. A 2007 investment analysis of Australian companies reported an association between lower scores in workplace health and safety indices and lower returns in the share market, but that analysis did not explore the role of energy costs (if any) in that relationship (Gray, 2007). There are a number of theoretical mechanisms that might explain this finding. For example, ambulance service employees would individually face the same increases in energy prices, and they might choose to work additional overtime shifts or take on second jobs to bolster their household budgets. Extra work hours—whether in their primary job or a second job—could lead to worker fatigue, which is associated with increased risk of workplace injury and fatality among ambulance personnel (Maguire 2011; Maguire, Hunting, Smith, & Levick, 2002; Patterson et al., 2012; Studnek & Fernandez, 2008).

Finally, increasing diesel price was associated with an increase in median response time in the following year, and the same positive association between fuel prices and median response time was seen when modelling lagged oil price instead of lagged diesel price. While there are very few emergencies for which an association between rapid ambulance response and decreased mortality has been demonstrated (Blackwell & Kaufman, 2002; Blanchard et al., 2012; De Maio, Stiell, Wells, & Spaite, 2003; Pons et al., 2005; Pons & Markovchick, 2002), most ambulance systems are still expected to meet rigid response time standards. This requires considerable resources in the form of vehicles, stations, and personnel. This study now provides empirical data supporting the intuitive notion that the erosion of ambulance service resources by increasing energy prices eventually results in delayed ambulance response times.

6.7 Limitations and Future Studies

One limitation of this study is that diesel price data were only available for the most recent six year period, so world crude oil price was included as an indirect measure of vehicle fuel costs. However, despite the different time spans for which the diesel and oil price data were available, little variation in the results was observed when modelling the effects of the two energy sources. The coefficients, the significance of the findings, and the explained variances in the models were nearly identical for the analyses of diesel and electricity prices compared with those for oil and electricity prices. While adding the oil price data to the analyses did not meaningfully alter the outcome, this was not wasted effort; the consistency of the results adds to the confidence in the findings.

Another potential limitation is that this analysis depends on summary data extracted from annual reports of the ambulance agencies or their parent organisations, rather than data specifically collected for this study. Also, data for ambulance-related activities that are not delivered by the states and territories, most notably the Royal Flying Doctor Service but also other small independent agencies, are not included in this analysis. These are, however, non-differential information biases that would result in bias towards the null hypothesis.

That complete electricity price data were not available for all states and territories is another limitation of this study. The results of the separate analyses of the data for the two jurisdictions without electricity price data do differ from those of the main analyses, but they do not contradict the main findings. In fact, although it was a lagged rather than contemporaneous effect, increasing diesel and oil prices were associated with decreased resource allocation in those two ambulance systems as well.

Lastly, these are aggregate-level ecological data (in the epidemiologic sense) on an annual scale; they cannot be extrapolated to individual ambulance responses, or to shorter-run (for example, weekly or monthly) changes in energy prices.

Future studies might seek to explain the exact mechanisms of the effects observed in this study. Ambulance services involve vehicles, equipment, buildings, communication systems, and personnel, as well as information technology systems, clinical training activities, physician oversight, and administrative structures (Lerner, Nichol, Spaite, Garrison, & Maio, 2007). Fluctuating energy prices could conceivably impact any or all of these inter-related components. It is also possible that ambulance services are able to achieve efficiencies in the face of rising energy prices so that the resource, operational and safety insults identified in this study do not diminish patient care, but further study is needed to explicitly explore the effects of rising energy costs on patient outcomes. The effects of energy costs on ambulance systems in other countries, particularly those where ambulance services operate as free-market enterprises, also remain to be determined. More broadly, the impact of energy scarcity and rising prices on other aspects of the health care system is an area in need of substantial research.

6.8 Conclusion

This study was undertaken to empirically evaluate the impact of energy price fluctuations on ambulance services. The main finding of this analysis is that the null hypothesis is rejected: there is an association between energy prices and Australian ambulance service resource, operational and safety performance characteristics. Diesel prices and oil prices have a contemporaneous inverse relationship with expenditures per response and FTE per 10,000 responses in most states, and a lagged inverse relationship with resource measures in other states; that is, higher energy prices are associated with diminished resource allocation. There is also a one-year lagged association between increasing diesel and oil prices and increasing median ambulance response times. Finally, there is a contemporaneous association between higher electricity prices and increasing injury compensation claims that is seen whether electricity price is modelled simultaneously with diesel price or oil price.

Chapter 7: Summary Discussion and Concluding Remarks

The previous four chapters have reviewed the literature related to health-related emissions, described the Scope 1 and Scope 2 greenhouse gas emissions of Australian ambulance operations, estimated their complete life cycle emissions, and demonstrated that their energy consumption is not only an environmental issue, but also an economic concern. This chapter summarises the key findings of this thesis, discusses their relevance to Australian ambulance systems, and provides some suggestions for future research.

Portions of this chapter (sections 7.3 and 7.4) have been partially adapted from the manuscript: Brown, L.H., Blanchard, I.E. (2012). Energy, emissions, and emergency medical services: Policy matters. *Energy Policy*, 46, 585-593. The published version of the paper is reproduced in Appendix 3.

7.1 Summary of Findings

7.1.1 Health Systems Emissions

The greenhouse gas emissions of health systems and health related activities are not widely studied; the literature review identified only 32 studies explicitly evaluating the energy consumption or environmental impacts of health services. What is known from the literature is that on a per-event or per-patient basis, health related emissions are small, usually measured on the order of tens or hundreds of kg CO_2e per patient. In the aggregate, however, health sector emissions are substantial, representing 3% of total greenhouse gas emissions in England (Sustainable Development Commission-Stockholm Environment Institute, 2008) and 8% of total emissions in the U.S. (Chung & Meltzer, 2009).

Prior to this thesis, the only published works on EMS-related emissions were from North America, where Scope 1 and Scope 2 emissions were estimated to average 45.5 kg CO_2e per ambulance response. Vehicle fuels accounted for 72% of emissions from ground EMS operations in North America, with electricity consumption responsible for 20% of emissions and other fuels making up the remainder. For the U.S., annual emissions from ground EMS activities were estimated at 660,000 to 1.6 million t CO_2e. Emissions from air medical activities were much greater than for ground EMS activities, estimated at approximately 1 t CO_2e per air ambulance mission (Blanchard & Brown, 2011).

7.1.2 Scope 1 and Scope 2 Emissions from Australian Ambulance Services

The Scope 1 and 2 emissions from Australian ambulance operations compare favourably to those of North American EMS systems; for ground ambulance operations they are estimated at 22 kg CO_2e per response. In the aggregate, Australian state and territory based ambulance services are estimated to emit approximately 110,000 to 120,000 t of Scope 1 and Scope 2 greenhouse gases each year. While this represents a small proportion of total Australian emissions, it is of the same order as other important subsectors of the Australian economy.

Interestingly, electricity consumption is responsible for a larger share of Australian ground ambulance services' Scope 1 and Scope 2 emissions when compared with North America: approximately 41% vs. 20%. Also, on a per-patient basis, emissions from Australian air ambulance services are approximately five times those of North American air ambulance services.

7.1.3 Complete Life Cycle Emissions of Australian Ambulance Services

The complete life cycle emissions of Australian ambulance services are estimated to total between approximately 216,000 and 547,000 t CO_2e per year. While this seems a large range, it provides a useful—if inexact—indication of the scale of EMS related emissions in Australia. They represent between 1.8% and 4.4% of all Australian health sector emissions. As ambulance-related expenditures represent 1.7% of total health sector expenditures, ambulance services are likely responsible for a disproportionate share of health sector emissions, and thus might be able to play a meaningful role in efforts to reduce health sector emissions.

Scope 1 emissions represent approximately 20% of complete life cycle emissions from Australian ambulance systems, with Scope 2 electricity consumption responsible for 22% of emissions and upstream Scope 3 emissions accounting for 58%. Depending on whether the economic structures of Australian ambulance systems more closely resemble the remainder of the 'health services' sector, the 'other services' sector (which includes police and fire services), or the 'government services' sector, the leading structural paths contributing to their complete life cycle emissions would include such intuitive and counter-intuitive things as: basic chemicals; wholesale trade; gas production and distribution; lime; sheep and shorn wool; beef cattle for meat products; air and space transport; pulp, paper and paperboard; and softwoods for pulp, paper and paperboard (Foran, Lenzen, & Dey, 2005).

7.1.4 Energy Costs and Australian Ambulance Systems

Environmental concerns are not the only reason for Australian ambulance systems to evaluate and manage their energy consumption. Energy costs have a demonstrable impact on Australian ambulance services. A 20 cent per L increase in diesel price is associated with a $55 per ambulance response decrease in ambulance service expenditures; it is also associated with a staffing decrease of 1.5 FTE per 10,000 responses. In the year following a 20 cent per L increase in diesel price, median response times increase by 30 seconds. A 2 cent per kWh increase in electricity price is associated with an increase of three to four injury claims per 100 FTE annually.

While the mechanisms by which these effects occur remain to be determined, they do indicate that rising energy costs can adversely affect ambulance operations in ways that potentially impact both patients and ambulance service personnel. In this research, the influence of energy costs was measured only in the short run—that is, in the same year or first year after the price changes occurred. The long-run effects of energy prices on ambulance services, as well as the effects of persistent price increases (as opposed to price fluctuations), remain to be determined.

7.2 Relevance of the Findings

What do Australian ambulance operations take from this research? How can these data be used to foster the sustainability of Australian emergency ambulance operations?

First, while these data demonstrate that ambulance services are not, on a national scale, ‘big emitters’, they do produce a meaningful amount of greenhouse gas emissions. Policy efforts to constrain greenhouse gas emissions will affect Australian ambulance systems.

Second, in terms of the Scope 1 and Scope 2 emissions most easily influenced by EMS systems, consumption of vehicle fuels is the primary contributor to the carbon footprint of Australian ambulance systems, but electricity consumption is also responsible for a substantial portion their emissions. Efforts to minimise the carbon footprint of Australian ambulance services and ensure their environmental sustainability should target both of these energy sources.

Third, the direct emissions from air ambulance transport are approximately 200 times those of ground ambulance transport. Optimising the use of air medical resources is another potential strategy for reducing ambulance system emissions and energy consumption.

Fourth, the complete life cycle emissions of Australian ambulance services, including the upstream emissions from products and services in the supply chain, total approximately 216,000 to 547,000 t CO_2e each year, and account for between 1.8% and 4.4% of total Australian health sector emissions. This means ambulance services could make a meaningful contribution in efforts to reduce health sector emissions—which could be both an opportunity and a threat.

Fifth, around 60% of ambulance service complete life cycle emissions arise from upstream, Scope 3, processes. Implementing environmentally friendly purchasing practices would be required to achieve substantial reductions in the complete life cycle emissions of ambulance services. The upstream products and services that contribute most to the complete life cycle emissions of ambulance services include some products and services that are not intuitively linked to ambulance services. Advocating for green electricity generation, which could reduce emissions at all stages of the supply chain, is one way ambulance systems could reduce their complete life cycle emissions.

Sixth, energy consumption is not only an environmental issue for Australian ambulance systems. Energy costs have measurable effects on ambulance service resource, operational, and safety measures that could impact both patient care and employee well-being. Managing greenhouse gas emissions is managing energy consumption, and vice-versa. That is, there are both environmental and economic aspects to the 'sustainability' of Australian ambulance operations.

7.3 Strategies for Reducing the Energy and Environmental Burden of Ambulance Services

There are a number of strategies that ambulance agencies could adopt to reduce their energy consumption and greenhouse gas emissions and facilitate their adaptation to a low(er) carbon economy. Generally these can be described in the context of the 'IPAT' equation. While the IPAT equation primarily describes functions on an economy-wide level, the principles can also be applied to economic subsectors or individual enterprises (Waggoner & Ausubel, 2002; York, Rosa, & Dietz, 2003). That is, ambulance services can reduce their environmental impact ('I') by addressing the amount of service delivered (‘P’ - production), the structure of the EMS system (‘A’ - affluence) and technological innovations (‘T’) (Table 7.1).

Table 7.1: The IPAT equation.

Representation:	$I = f(P)x(A)x(T)$
Explanation:	Impact (I) is a function of population [or production] (P), affluence [or structure] (A), and technology (T).
Components:	
Emissions	I
Population/Production	P
Affluence/Structure	A
Technology	T
EMS Examples:	
Production	number of responses; number of transports; population served
Structure	single or tiered response; dynamic or static deployment
Technology	use of hybrid vehicles; use of bio-fuels

For example, the judicious use of transports to specialty centres would be a production strategy that could reduce ambulance transport distances, and thus their Scope 1 greenhouse gas emissions (Zander, Niggebrugge, Pencheon, & Lyratzopoulos, 2011). Reducing unnecessary ambulance responses and ambulance transports would be another production-related strategy (Hess & Greenberg, 2011), as would limiting the use of air-medical resources, whether rotor-wing or fixed-wing, to only those situations in which they are demonstrated to provide some clinical benefit. One difficulty with such a strategy is that medical necessity is not well defined (Cone, Schmidt, Mann, & Brown, 2004; Hauswald & Jambrosic, 2004; Patterson, Moore, Brice, & Baxley, 2006), and not easily determined by emergency centre call takers (Schmidt, Cone, & Mann, 2004; Shah, Bishop, Lerner, Fairbanks, & Davis, 2005) or paramedics (Brown et al., 2009; Snooks, Dale, Hartley-Sharpe, & Halter, 2004). Further, in most developed countries there is a societal expectation of service on demand that would need to be addressed. Also, particularly in Australia, some emergency responses and transports require air-medical resources for logistical reasons, independent of patient condition.

Health promotion and injury/illness prevention initiatives, such as those targeting heart disease and motor vehicle crashes, would be indirect production-related strategies with the dual benefits of improved public health and reduced demand for ambulance transport.

An example of a structure-related strategy would be to change the way ambulance systems respond to emergency calls. Presently, most EMS systems must meet rigid response time standards for all unscheduled calls (Bailey & Sweeney, 2003; Myers et al., 2008)—which requires considerable resources in the form of vehicles, stations, and personnel—even though there are very few emergencies for which an association between rapid EMS response and decreased morbidity or mortality has been demonstrated (Blackwell & Kaufman, 2002; Blanchard et al., 2012; De Maio, Stiell, Wells, & Spaite, 2003; Pons et al., 2005; Pons & Markovchick, 2002). Response time policies that support responding to individual situations in the optimal amount of time, instead of all situations in a uniformly short amount of time, could reduce EMS system resource requirements (Eisenberg, Bergner, & Hallstrom, 1979) and thus energy consumption and emissions. Reducing driving speeds when transporting stable patients without life-threatening conditions to hospital might also reduce energy consumption and emissions. Driving ambulances with the flow of traffic, without warning lights and sirens, only marginally increases ambulance transport times (Brown, Whitney, Hunt, Addario, & Hogue, 2000; Hunt et al., 1995).

Another strategy would be reduced ambulance idling at emergency scenes and hospitals. Many EMS agencies are reluctant to shut down ambulances at emergency scenes, as the ambulance warning lights provide some measure of safety. Reducing idling at receiving hospitals, however, might be effective in reducing energy consumption and emissions given the extended off-load times confronting many EMS systems as a result of emergency department overcrowding (Eckstein et al., 2005; Vandeventer et al., 2011). A structural aspect of ambulance systems in particular need of research is the relative energy consumption and emissions profiles of fixed-station versus dynamic deployment staging strategies (the two predominant types of deployment strategy used in EMS). A fixed-station strategy has the added energy burden of stationhouses and usually longer response distances; a dynamic deployment strategy has the added fuel consumption of ambulances being constantly relocated to street-corner posts in order to minimise response distances and response times.

As thoroughly discussed in Chapter 5, technology-related strategies would include the use of hydrogen FCV ambulances (Burtt, 2008) and/or electric or hybrid vehicles for administrative and support vehicle fleets (Hawkins, 2008). However, while hydrogen FCV and electric vehicles have lower tailpipe emissions, their true environmental impact ultimately depends on local electricity generation processes (Leaver & Gillingham 2010; McCarthy & Yang, 2010; Ozalp, Epstein, & Kogan, 2010; Perujo & Ciuffo, 2010; Pro, Hammerschlag, & Mazza, 2005; Sioshansi, Fagiani, & Marano, 2010; Vergragt & Brown, 2007). Similarly, the use of bio-diesel would be a technology related strategy, but as with hydrogen FCV and electric vehicles, bio-fuels are not universally carbon-neutral (Searchinger et al., 2008; Solomon, 2010), and availability of sufficient quantities, particularly in rural areas, might also be a limitation on such a strategy.

Expanded utilisation of telemedicine is a technology-related strategy that might also be able to reduce the need to transport some patients (Patterson, 2005; Smith et al., 2007; Smith, Patterson, & Scott, 2007; Yellowlees, Chorba, Parish, Wynn-Jones, & Nafiz, 2010). Finally, using electronic (rather than paper) forms for medical records and research activities can also reduce the environmental burden of health services, including ambulance services (Chakladar, Eckstein, & White, 2011; Turley et al., 2011).

There are certainly other potential strategies for reducing ambulance-related energy consumption and emissions. Importantly, however, none of these proposed strategies have been empirically evaluated; their actual impact on energy consumption, emissions and patient outcomes, as well as their social acceptability, remain to be determined.

7.4 Directions for the Future

A number of questions remain to be answered: What efforts are Australian ambulance services already undertaking to reduce their greenhouse gas emissions? What barriers do those efforts face? How effective are those strategies? Future research could also attempt an inventory based assessment of the complete life cycle emissions of Australian ambulance services, allowing a more specific evaluation of the structural paths contributing to those emissions.

Also, while this thesis focuses on Australian ambulance services, these are international issues. What are the Scope 1, Scope 2 and complete life cycle emissions of ambulance services in other countries? How do they compare with those of Australian and North American EMS systems? Are there specific ambulance system characteristics that are associated with higher or lower emissions profiles? Are the energy and environmental issues for EMS systems representative of, and instructive for, other aspects of the health system?

Finally, the specific strategies discussed in Section 7.3 above—and any other proposed strategies—will require evaluation. For example: Does accelerating a fleet replacement schedule, replacing older low-efficiency vehicles with modern high-efficiency vehicles, significantly reduce Scope 1 emissions? What effect does such a strategy have on complete life cycle emissions? Do ambulance services with flexible response time requirements have lower emissions profiles than those with shorter, more stringent response time standards?

There is much more to be done. Some of these future studies are already underway; some are being planned; some will have to be left to others to complete. As I wrote at the beginning of this thesis, “This is the commencement—not the culmination—of an effort to ensure the sustainability of EMS systems”. The conclusion of this thesis is not the resolution of this issue, and it is not the end of my research in this area.

Another door has opened....

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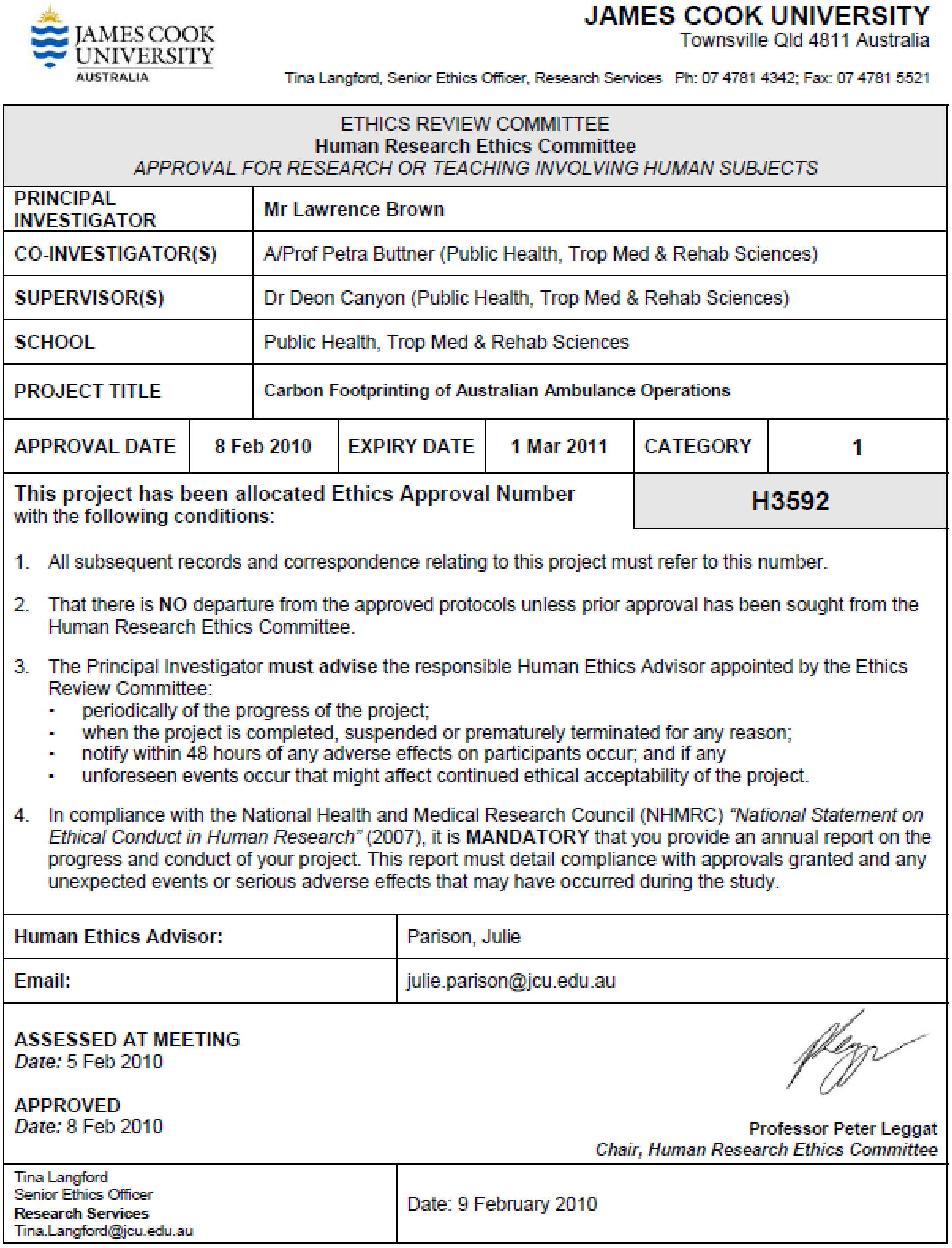
Appendix 1: Ethics Approvals



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Tina Langford, Senior Ethics Officer, Research Services Ph: 07 4781 4342; Fax: 07 4781 5521

ETHICS REVIEW COMMITTEE
Human Research Ethics Committee
APPROVAL FOR RESEARCH OR TEACHING INVOLVING HUMAN SUBJECTS

PRINCIPAL INVESTIGATOR	**Mr Lawrence Brown**
CO-INVESTIGATOR(S)	A/Prof Petra Buttner (Public Health, Trop Med & Rehab Sciences)
SUPERVISOR(S)	Dr Deon Canyon (Public Health, Trop Med & Rehab Sciences)
SCHOOL	Public Health, Trop Med & Rehab Sciences
PROJECT TITLE	**Carbon Footprinting of Australian Ambulance Operations**

APPROVAL DATE	**8 Feb 2010**	EXPIRY DATE	**1 Mar 2011**	CATEGORY	**1**

This project has been allocated Ethics Approval Number **H3592**
with the **following conditions**:

1. All subsequent records and correspondence relating to this project must refer to this number.
2. That there is **NO** departure from the approved protocols unless prior approval has been sought from the Human Research Ethics Committee.
3. The Principal Investigator **must advise** the responsible Human Ethics Advisor appointed by the Ethics Review Committee:
   - periodically of the progress of the project;
   - when the project is completed, suspended or prematurely terminated for any reason;
   - notify within 48 hours of any adverse effects on participants occur; and if any
   - unforeseen events occur that might affect continued ethical acceptability of the project.
4. In compliance with the National Health and Medical Research Council (NHMRC) *"National Statement on Ethical Conduct in Human Research"* (2007), it is **MANDATORY** that you provide an annual report on the progress and conduct of your project. This report must detail compliance with approvals granted and any unexpected events or serious adverse effects that may have occurred during the study.

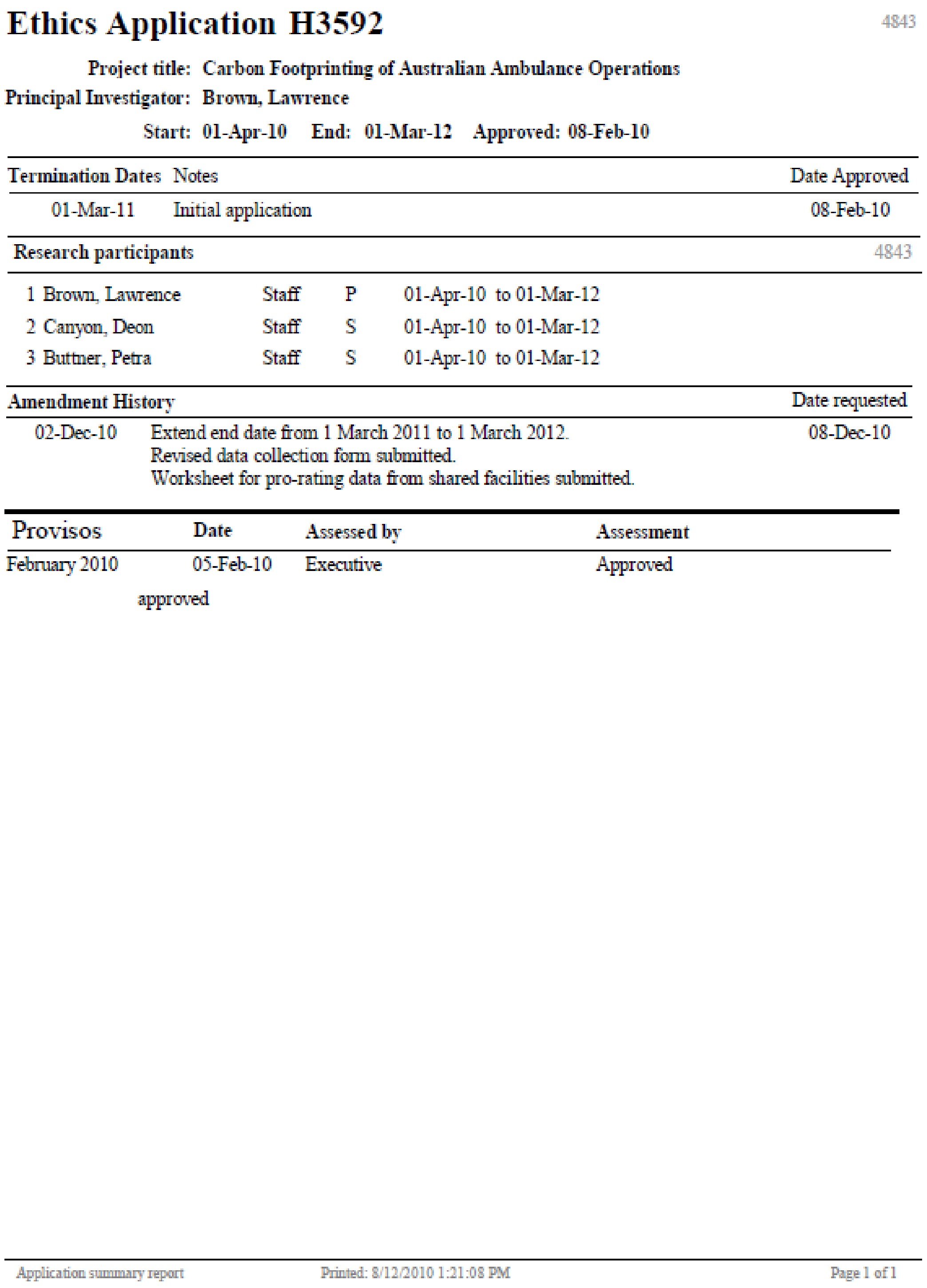
Human Ethics Advisor:	Parison, Julie
Email:	julie.parison@jcu.edu.au

ASSESSED AT MEETING
Date: 5 Feb 2010

APPROVED
Date: 8 Feb 2010

Professor Peter Leggat
Chair, Human Research Ethics Committee

Tina Langford Senior Ethics Officer **Research Services** Tina.Langford@jcu.edu.au	Date: 9 February 2010



Ethics Application H3592

4843

Project title: **Carbon Footprinting of Australian Ambulance Operations**
Principal Investigator: **Brown, Lawrence**
Start: **01-Apr-10** **End:** **01-Mar-12** **Approved:** **08-Feb-10**

Termination Dates	Notes	Date Approved
01-Mar-11	Initial application	08-Feb-10

Research participants 4843

1	Brown, Lawrence	Staff	P	01-Apr-10 to 01-Mar-12
2	Canyon, Deon	Staff	S	01-Apr-10 to 01-Mar-12
3	Buttner, Petra	Staff	S	01-Apr-10 to 01-Mar-12

Amendment History		Date requested
02-Dec-10	Extend end date from 1 March 2011 to 1 March 2012. Revised data collection form submitted. Worksheet for pro-rating data from shared facilities submitted.	08-Dec-10

Provisos	**Date**	**Assessed by**	**Assessment**
February 2010	05-Feb-10	Executive	Approved

approved

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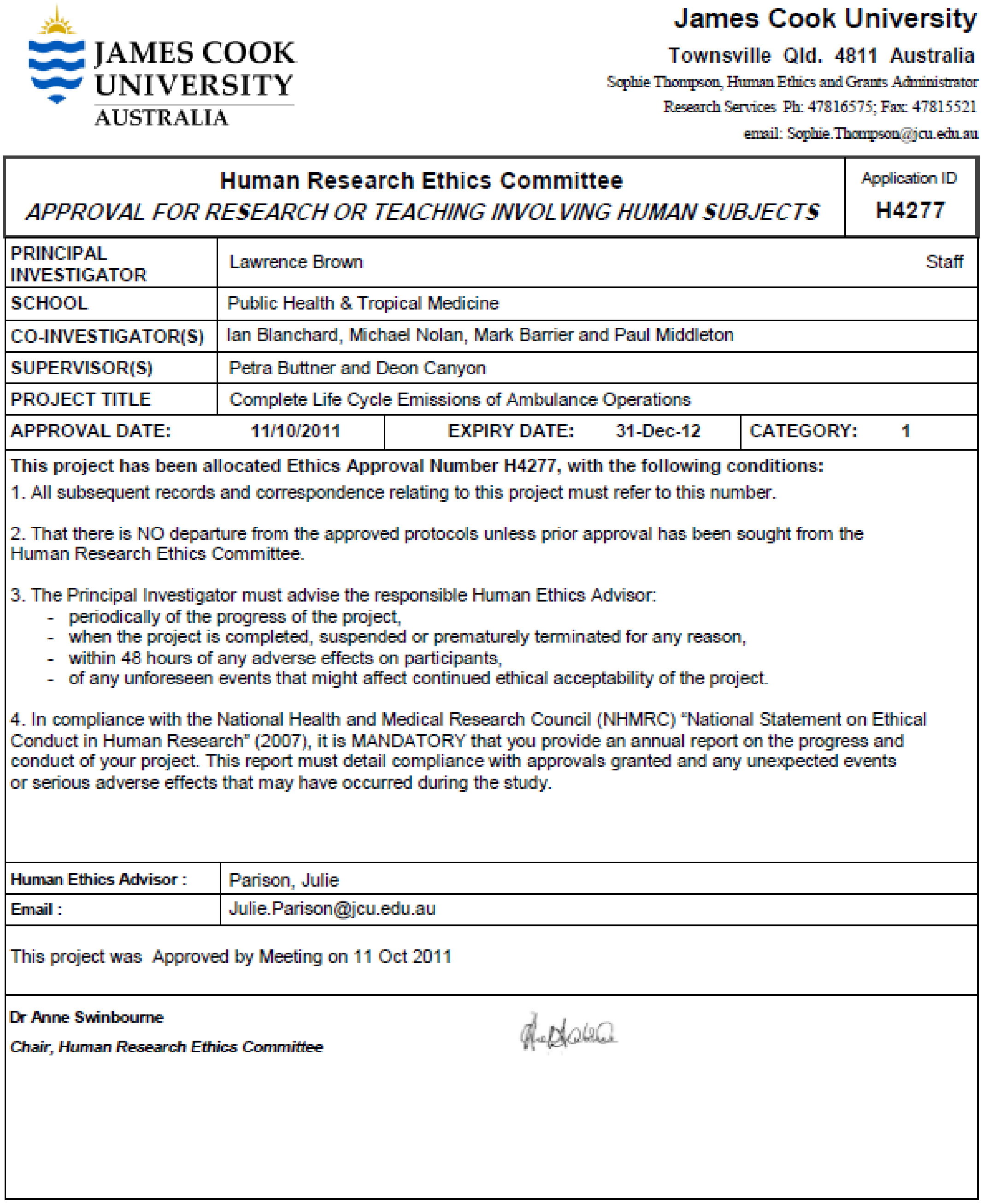

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James Cook University
Townsville Qld. 4811 Australia
Sophie Thompson, Human Ethics and Grants Administrator
Research Services Ph: 47816575; Fax: 47815521
email: Sophie.Thompson@jcu.edu.au

Human Research Ethics Committee *APPROVAL FOR RESEARCH OR TEACHING INVOLVING HUMAN SUBJECTS*	Application ID **H4277**

PRINCIPAL INVESTIGATOR	Lawrence Brown	Staff
SCHOOL	Public Health & Tropical Medicine	
CO-INVESTIGATOR(S)	Ian Blanchard, Michael Nolan, Mark Barrier and Paul Middleton	
SUPERVISOR(S)	Petra Buttner and Deon Canyon	
PROJECT TITLE	Complete Life Cycle Emissions of Ambulance Operations	

APPROVAL DATE:	11/10/2011	EXPIRY DATE:	31-Dec-12	CATEGORY:	1

This project has been allocated Ethics Approval Number H4277, with the following conditions:

1. All subsequent records and correspondence relating to this project must refer to this number.

2. That there is NO departure from the approved protocols unless prior approval has been sought from the Human Research Ethics Committee.

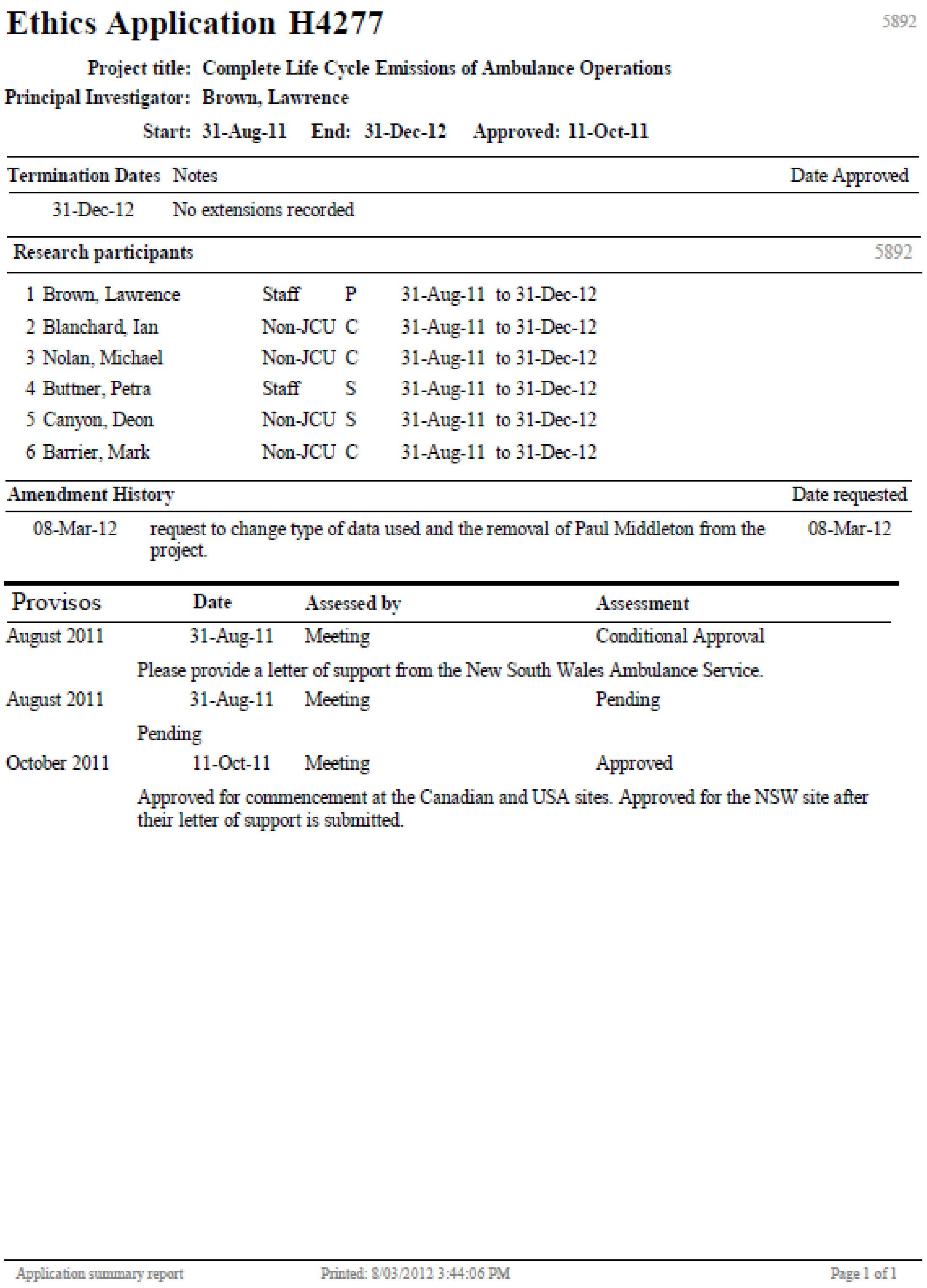
3. The Principal Investigator must advise the responsible Human Ethics Advisor:
   - periodically of the progress of the project,
   - when the project is completed, suspended or prematurely terminated for any reason,
   - within 48 hours of any adverse effects on participants,
   - of any unforeseen events that might affect continued ethical acceptability of the project.

4. In compliance with the National Health and Medical Research Council (NHMRC) "National Statement on Ethical Conduct in Human Research" (2007), it is MANDATORY that you provide an annual report on the progress and conduct of your project. This report must detail compliance with approvals granted and any unexpected events or serious adverse effects that may have occurred during the study.

Human Ethics Advisor :	Parison, Julie
Email :	Julie.Parison@jcu.edu.au

This project was Approved by Meeting on 11 Oct 2011

Dr Anne Swinbourne
Chair, Human Research Ethics Committee



Ethics Application H4277

5892

Project title: **Complete Life Cycle Emissions of Ambulance Operations**
Principal Investigator: **Brown, Lawrence**
Start: **31-Aug-11** **End:** **31-Dec-12** **Approved:** **11-Oct-11**

Termination Dates	Notes	Date Approved
31-Dec-12	No extensions recorded	

Research participants 5892

1	Brown, Lawrence	Staff	P	31-Aug-11	to 31-Dec-12
2	Blanchard, Ian	Non-JCU	C	31-Aug-11	to 31-Dec-12
3	Nolan, Michael	Non-JCU	C	31-Aug-11	to 31-Dec-12
4	Buttner, Petra	Staff	S	31-Aug-11	to 31-Dec-12
5	Canyon, Deon	Non-JCU	S	31-Aug-11	to 31-Dec-12
6	Barrier, Mark	Non-JCU	C	31-Aug-11	to 31-Dec-12

Amendment History		Date requested
08-Mar-12	request to change type of data used and the removal of Paul Middleton from the project.	08-Mar-12

Provisos	**Date**	**Assessed by**	**Assessment**
August 2011	31-Aug-11	Meeting	Conditional Approval
	Please provide a letter of support from the New South Wales Ambulance Service.		
August 2011	31-Aug-11	Meeting	Pending
	Pending		
October 2011	11-Oct-11	Meeting	Approved
	Approved for commencement at the Canadian and USA sites. Approved for the NSW site after their letter of support is submitted.		

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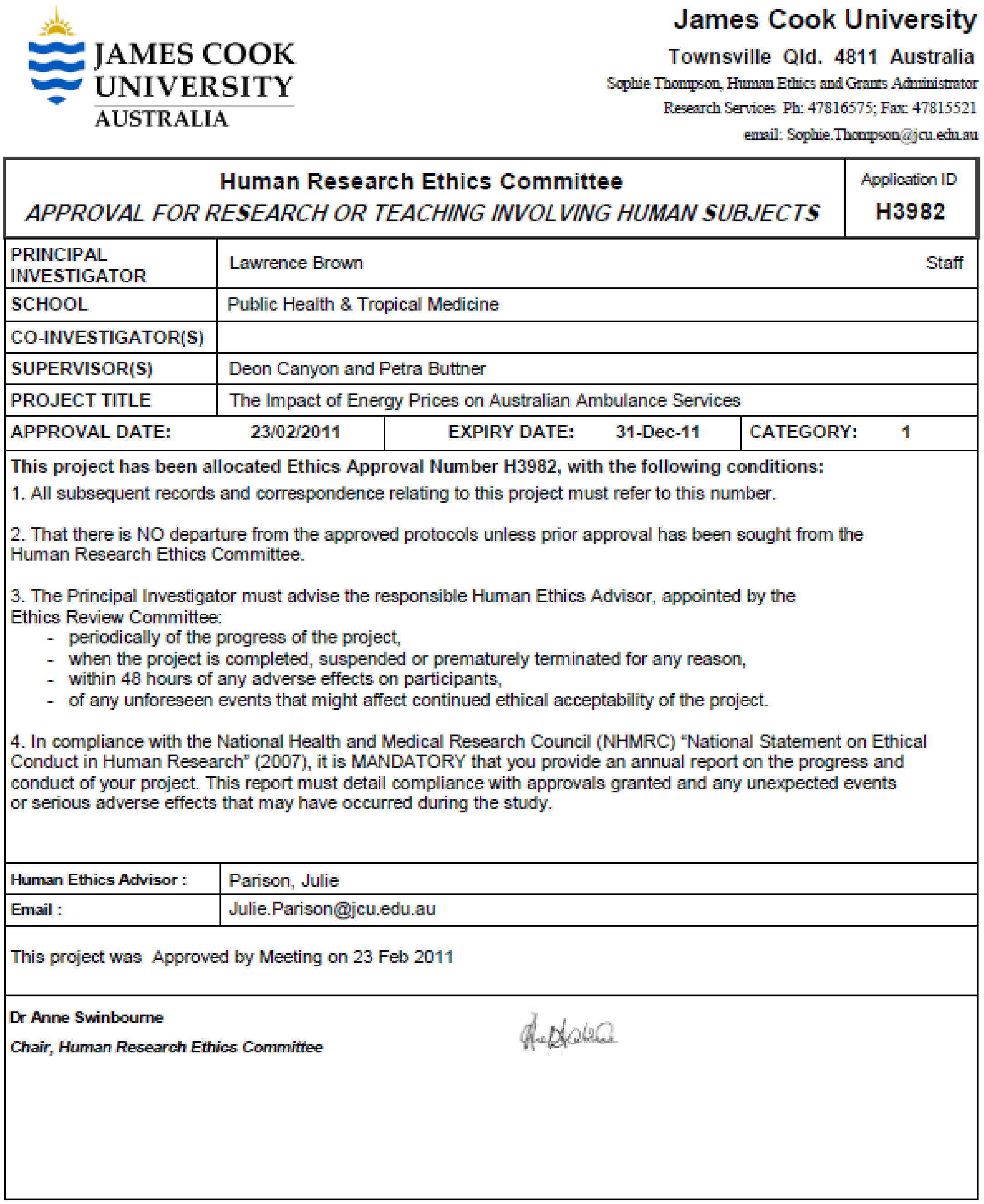

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Human Research Ethics Committee *APPROVAL FOR RESEARCH OR TEACHING INVOLVING HUMAN SUBJECTS*	Application ID **H3982**

PRINCIPAL INVESTIGATOR	Lawrence Brown	Staff
SCHOOL	Public Health & Tropical Medicine	
CO-INVESTIGATOR(S)		
SUPERVISOR(S)	Deon Canyon and Petra Buttner	
PROJECT TITLE	The Impact of Energy Prices on Australian Ambulance Services	

APPROVAL DATE:	23/02/2011	EXPIRY DATE:	31-Dec-11	CATEGORY:	1

This project has been allocated Ethics Approval Number H3982, with the following conditions:

1. All subsequent records and correspondence relating to this project must refer to this number.

2. That there is NO departure from the approved protocols unless prior approval has been sought from the Human Research Ethics Committee.

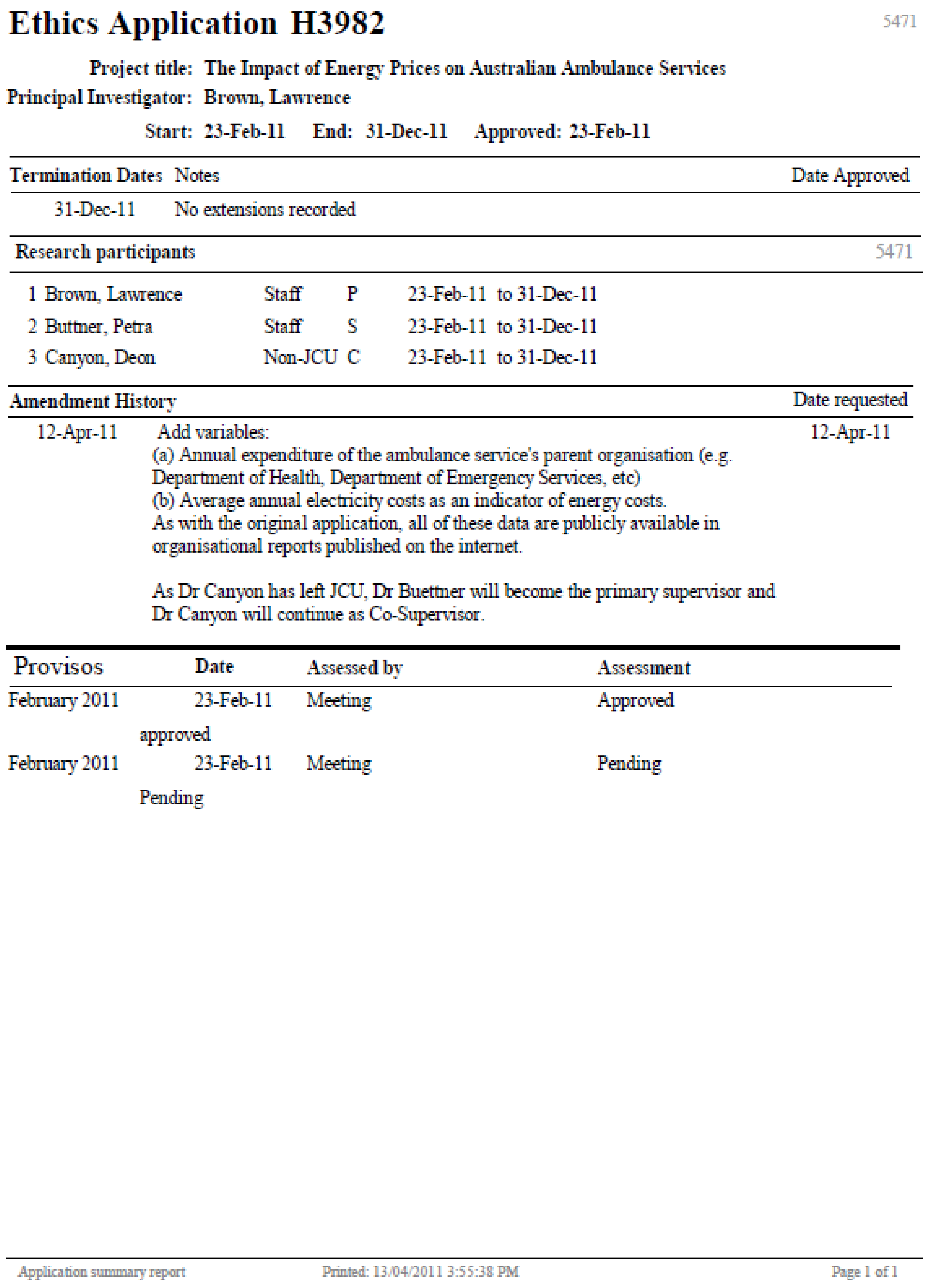
3. The Principal Investigator must advise the responsible Human Ethics Advisor, appointed by the Ethics Review Committee:
   - periodically of the progress of the project,
   - when the project is completed, suspended or prematurely terminated for any reason,
   - within 48 hours of any adverse effects on participants,
   - of any unforeseen events that might affect continued ethical acceptability of the project.

4. In compliance with the National Health and Medical Research Council (NHMRC) “National Statement on Ethical Conduct in Human Research” (2007), it is MANDATORY that you provide an annual report on the progress and conduct of your project. This report must detail compliance with approvals granted and any unexpected events or serious adverse effects that may have occurred during the study.

Human Ethics Advisor :	Parison, Julie
Email :	Julie.Parison@jcu.edu.au

This project was Approved by Meeting on 23 Feb 2011

Dr Anne Swinbourne
Chair, Human Research Ethics Committee



Ethics Application H3982

5471

Project title: **The Impact of Energy Prices on Australian Ambulance Services**
Principal Investigator: **Brown, Lawrence**
Start: **23-Feb-11** **End:** **31-Dec-11** **Approved:** **23-Feb-11**

Termination Dates	Notes	Date Approved
31-Dec-11	No extensions recorded	

Research participants 5471

1	Brown, Lawrence	Staff	P	23-Feb-11 to 31-Dec-11
2	Buttner, Petra	Staff	S	23-Feb-11 to 31-Dec-11
3	Canyon, Deon	Non-JCU	C	23-Feb-11 to 31-Dec-11

Amendment History		Date requested
12-Apr-11	Add variables: (a) Annual expenditure of the ambulance service's parent organisation (e.g. Department of Health, Department of Emergency Services, etc) (b) Average annual electricity costs as an indicator of energy costs. As with the original application, all of these data are publicly available in organisational reports published on the internet. As Dr Canyon has left JCU, Dr Buettner will become the primary supervisor and Dr Canyon will continue as Co-Supervisor.	12-Apr-11

Provisos	**Date**	**Assessed by**	**Assessment**
February 2011	23-Feb-11	Meeting	Approved
approved			
February 2011	23-Feb-11	Meeting	Pending
Pending			

Application summary report Printed: 13/04/2011 3:55:38 PM Page 1 of 1

Appendix 2: Documentation of Acceptance for Manuscripts in Press Arising from this Thesis

Brown, L.H., Canyon. D.V., Buettner, P.G. (In Press). The energy burden and environmental impact of health services: A review. *American Journal of Public Health*.

Brown, L.H., Canyon. D.V., Buettner. P.G., Crawford. J.M., Judd. J., on behalf of the Australian Ambulance Emissions Study Group. (In Press). The carbon footprint of Australian ambulance operations. *Emergency Medicine Australasia*.

From: em.ajph.0.2983db.ca33d00b@editorialmanager.com on behalf of ajph.submissions@apha.org
Sent: Monday, 5 March 2012 10:02 AM
To: Brown, Lawrence
Subject: Your Submission

CC: mrg@rci.rutgers.edu

Mar 04, 2012
Ref.: Ms. No. AJPH-20113028R1
The Energy Burden and Environmental Impact of Health Services: A Review American Journal of Public Health

Dear Mr. Lawrence Brown,

We are glad to be able to inform you that your paper has been accepted for publication in the American Journal of Public Health as a Research Article. Our Editorial and Production teams look forward to working with you during the copyediting, proofreading, and further query stages of the production process.

Your paper was accepted on Mar 04, 2012.

Any further comments from the Editors and Reviewers follow:

Reviewer #2: I feel satisfied with the changes that were made by the author

Reviewer #3: Thank you for the thorough responses. I have reviewed the changes addressing my previous comments and am satisfied with the revision.

The instructions below contain enough detail to ensure the production and publication of your paper proceed smoothly. Any final editorial and peer review comments ought to be addressed directly in the version that is uploaded for copyediting.

A. PRODUCTION NEEDS

You will be contacted via email by Teena Lucas when you can upload your final paper into the system along with any accompanying figure/image/table files. Please prepare your figure/image/table files so that they are in the format of the program in which they were originally created. For example, figures created in Excel should be saved and uploaded as .xls files. If files were created using statistical software, please save them from within the program as .eps or .pdf files. We are not able to work with flattened image files pasted into a Powerpoint or Word document. If tables were created in Word, please insert them at then end of the document, directly after the references.

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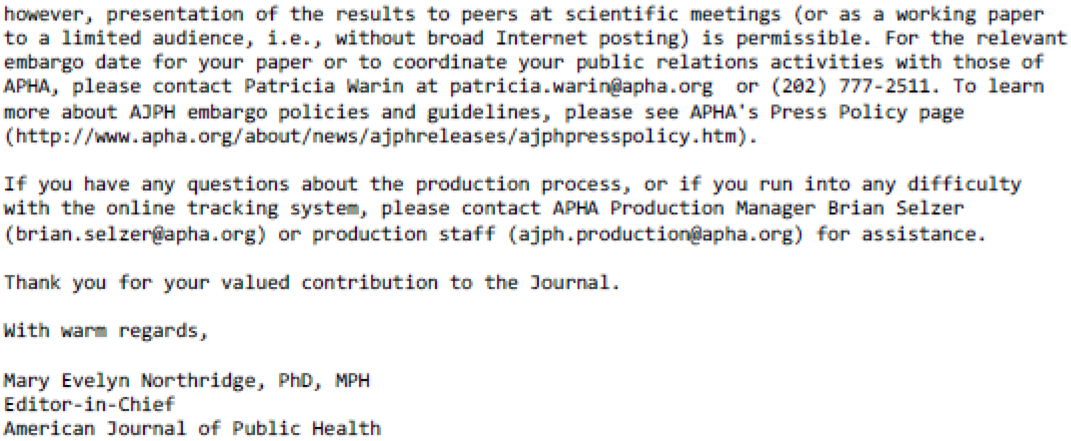

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With warm regards,

Mary Evelyn Northridge, PhD, MPH
Editor-in-Chief
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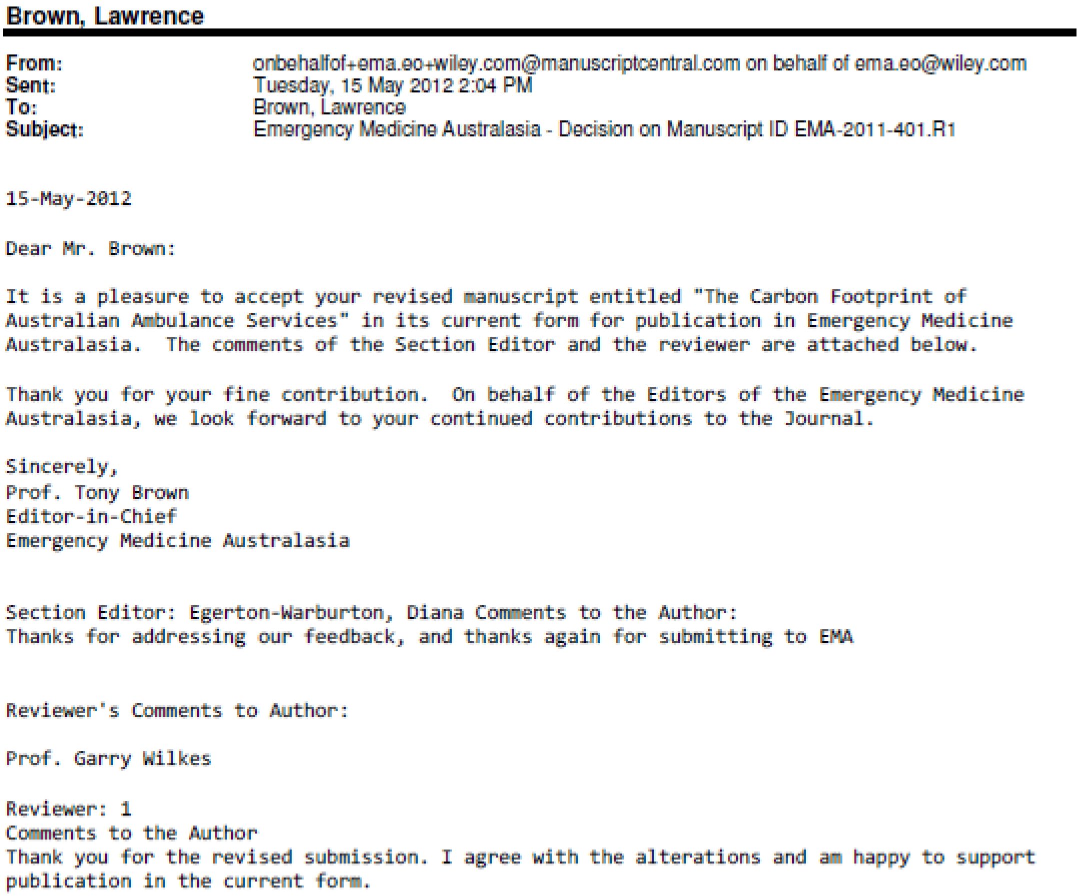


Brown, Lawrence

From: onbehalfof+ema.eo+wiley.com@manuscriptcentral.com on behalf of ema.eo@wiley.com
Sent: Tuesday, 15 May 2012 2:04 PM
To: Brown, Lawrence
Subject: Emergency Medicine Australasia - Decision on Manuscript ID EMA-2011-401.R1

15-May-2012

Dear Mr. Brown:

It is a pleasure to accept your revised manuscript entitled "The Carbon Footprint of Australian Ambulance Services" in its current form for publication in Emergency Medicine Australasia. The comments of the Section Editor and the reviewer are attached below.

Thank you for your fine contribution. On behalf of the Editors of the Emergency Medicine Australasia, we look forward to your continued contributions to the Journal.

Sincerely,
Prof. Tony Brown
Editor-in-Chief
Emergency Medicine Australasia

Section Editor: Egerton-Warburton, Diana Comments to the Author:
Thanks for addressing our feedback, and thanks again for submitting to EMA

Reviewer's Comments to Author:

Prof. Garry Wilkes

Reviewer: 1
Comments to the Author
Thank you for the revised submission. I agree with the alterations and am happy to support publication in the current form.

Appendix 3: Published Manuscripts Arising from or Contributing to this Thesis

Brown, L.H., Blanchard, I.E. (2012). Energy, emissions and emergency medical services: Policy matters. *Energy Policy*, 46, 585-593.

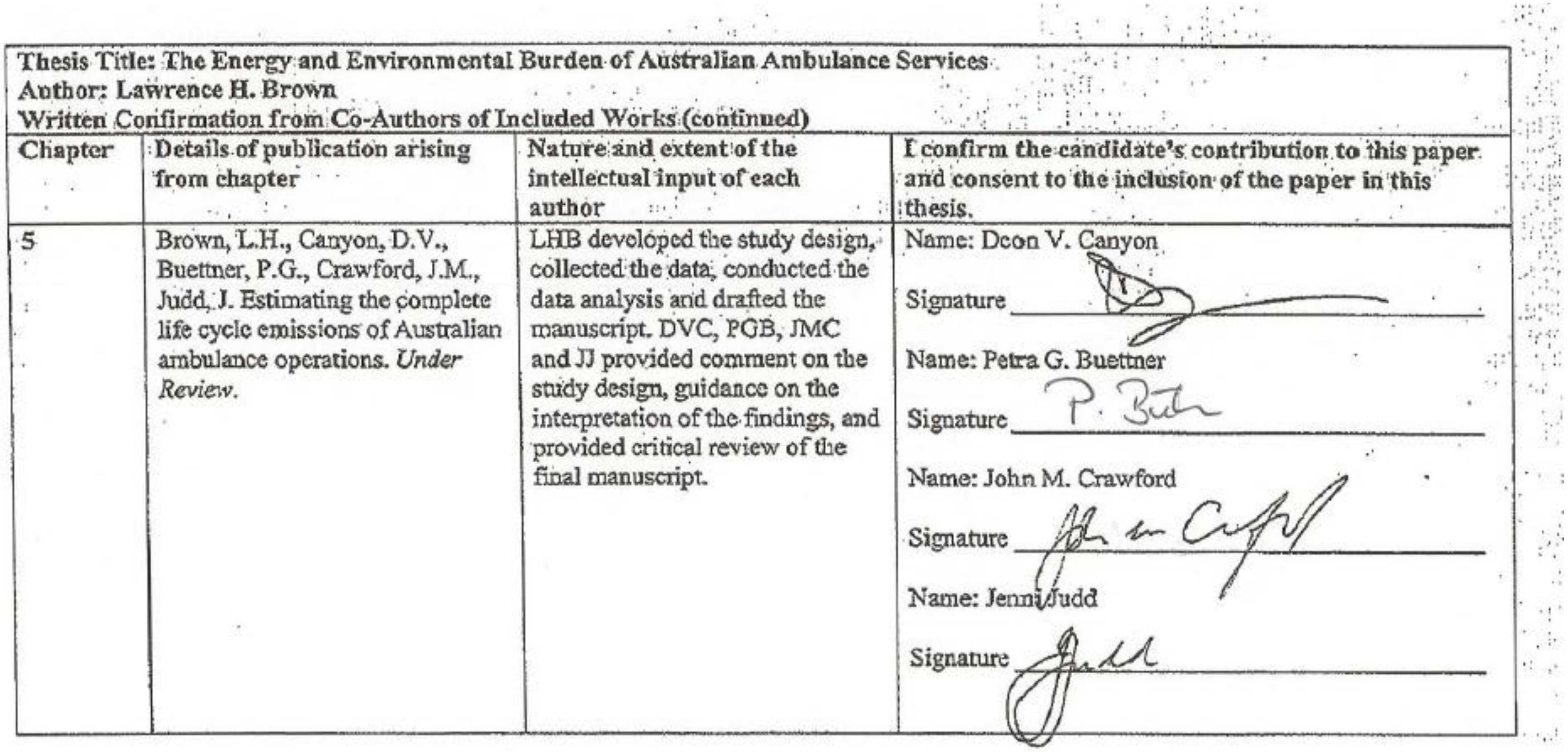
Appendix 4: Contributing Author Verification of Contributions to Manuscripts Arising from, Contributing to, or Relevant to but not Included in this Thesis

Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works

Chapter	Details of publication arising from chapter	Nature and extent of the intellectual input of each author	I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.
3	Brown, L.H., Canyon. D.V., Buettner, P.G. The energy burden and environmental impact of health services: A review. *American Journal of Public Health*. In Press.	LHB devised and executed the search strategy, reviewed the identified papers and extracted the relevant data, and drafted the manuscript. DVC and PGB reviewed and provided guidance on the search strategy, and provided critical review of the final manuscript.	Name: Deon V. Canyon Signature ________ Name: Petra G. Buettner Signature P. Buth

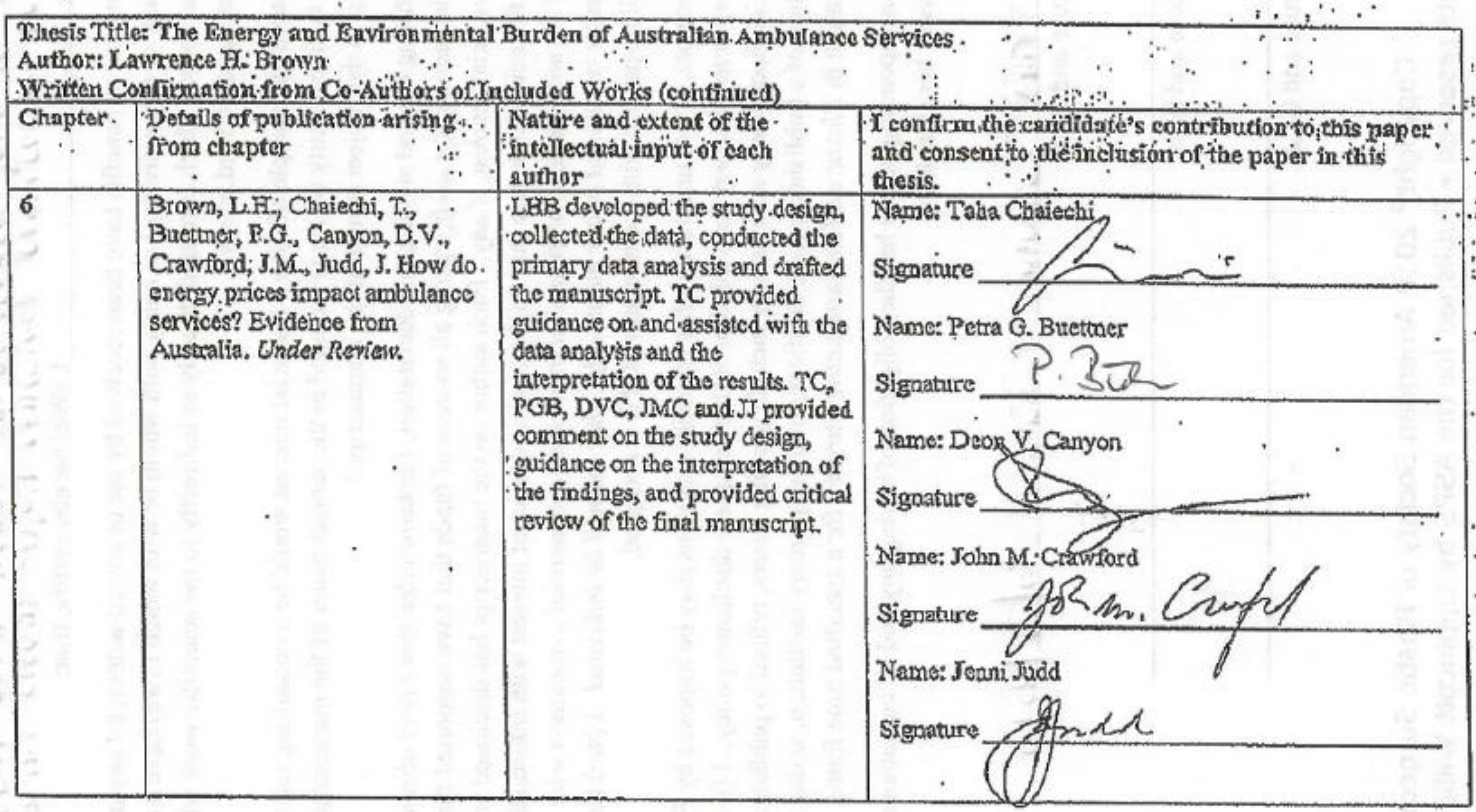
Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	**Details of publication arising from chapter**	**Nature and extent of the intellectual input of each author**	**I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.**
4	Brown, L.H., Canyon. D.V., Buettner. P.G., Crawford. J.M., Judd. J., on behalf of the Australian Ambulance Emissions Study Group. The carbon footprint of Australian ambulance operations. *Under Review.*	LHB developed the study design and data collection process, established the linkages with the participating organisations, conducted the data analysis and drafted the manuscript. DVC, PGB, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.	Name: Deon V. Canyon Signature _____ Name: Petra G. Buettner Signature _____ Name: John M. Crawford Signature _____ Name: Jenni Judd Signature _____



Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	Details of publication arising from chapter	Nature and extent of the intellectual input of each author	I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.
5	Brown, L.H., Canyon, D.V., Buettner, P.G., Crawford, J.M., Judd, J. Estimating the complete life cycle emissions of Australian ambulance operations. *Under Review.*	LHB developed the study design, collected the data, conducted the data analysis and drafted the manuscript. DVC, PGB, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.	Name: Deon V. Canyon Signature ________ Name: Petra G. Buettner Signature ________ Name: John M. Crawford Signature ________ Name: Jenni Judd Signature ________



Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	Details of publication arising from chapter	Nature and extent of the intellectual input of each author	I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.
6	Brown, L.H., Chaiechi, T., Buettner, P.G., Canyon, D.V., Crawford, J.M., Judd, J. How do energy prices impact ambulance services? Evidence from Australia. *Under Review.*	LHB developed the study design, collected the data, conducted the primary data analysis and drafted the manuscript. TC provided guidance on and assisted with the data analysis and the interpretation of the results. TC, PGB, DVC, JMC and JJ provided comment on the study design, guidance on the interpretation of the findings, and provided critical review of the final manuscript.	Name: Taha Chaiechi Signature ________ Name: Petra G. Buettner Signature ________ Name: Deon V. Canyon Signature ________ Name: John M. Crawford Signature ________ Name: Jenni Judd Signature ________

Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	Details of publication arising from chapter	Nature and extent of the intellectual input of each author	I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.
7 **(sections 7.3 & 7.4)**	Brown, L.H., Blanchard, I.E. (2012). Energy, emissions, and emergency medical services: Policy matters. *Energy Policy*, 46, 585-593.	Author contributions: LHB and IEB developed and executed this post hoc analysis. LHB drafted the manuscript; IEB provided critical review of the manuscript. A significant revision to the manuscript occurred as a result of the peer-review process. LHB and IEB contributed equally to that revision.	Name: Ian E. Blanchard Signature

Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	Details of publication included in appendix	Nature and extent of the intellectual input of each author	I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.
Appendix 5	Blanchard, I., Brown LH. (2009). Carbon footprinting of EMS systems: A proof of concept study. *Prehospital Emergency Care*, 13, 546-549.	Author contributions: LHB and IEB developed and executed the study. LHB drafted the manuscript; IEB provided critical review of the manuscript. LHB and IEB contributed equally to the final revision of the manuscript.	Name: Ian E. Blanchard Signature ______

Thesis Title: The Energy and Environmental Burden of Australian Ambulance Services
Author: Lawrence H. Brown
Written Confirmation from Co-Authors of Included Works (continued)

Chapter	**Details of publication included in appendix**	**Nature and extent of the intellectual input of each author**	**I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.**
Appendix 5	Blanchard, I.E., Brown LH. (2011). Carbon footprinting of North American emergency medical services systems. *Prehospital Emergency Care*, 15, 23-29.	Author contributions: LHB and IEB developed and executed the study. LHB drafted the manuscript; IEB provided critical review of the manuscript. LHB and IEB contributed equally to the final revision of the manuscript.	Name: Ian E. Blanchard Signature

Appendix 5: Relevant Manuscripts Published by the Author but not included in this Thesis

Blanchard, I., Brown, L.H. (2009). Carbon footprinting of EMS systems: A proof of concept study. *Prehospital Emergency Care*, 13, 546-549.

Blanchard, I.E., Brown, L.H., on behalf of the North American EMS Emissions Study Group. Carbon footprinting of North American EMS systems. (2011). *Prehospital Emergency Care*, 15, 23-29.

Appendix 6: Details of Articles Included in the Literature Review (Chapter 3).

Emergency Medical Services							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Blanchard & Brown	2009	Research	U.S., Canada	Evaluate ability of U.S. EMS agencies to report energy consumption required to calculate Scope 1 & 2 carbon footprint.	Retrospective: Two systems provided one year's energy consumption data. Conversion factors from U.S. EIA and EPA used to calculate carbon footprint.	Systems were able to report electricity, petrol and diesel consumption; one able to estimate commercial travel. Total emissions 5,000 t CO_2e.	Small proof of concept study; data limited to 2 systems, some energy consumption / travel pro-rated from larger accounts or estimated.
Blanchard & Brown	2011	Research	U.S., Canada	Determine the carbon footprint of North American EMS systems.	Retrospective: Collected energy consumption data from 15 systems. Conversion factors from U.S. EIA and EPA used to calculate carbon footprint. Per-capita and per-response emissions estimated, extrapolated to U.S. population.	Annual scope 2 emissions of 45.5 kg CO_2e / response; 3.7 kg CO_2e / resident. Extrapolated to U.S. = 660,000 to 1.6 million t CO_2e / year.	Convenience sample. Only 10 of 15 provided data to support Scope 2 carbon footprint calculation. Self reported data not verified
Hawkins	2008	Advocacy	U.S.	Describe use of a hybrid vehicle as an EMS response vehicle.	Anecdote: Author purchased vehicle for use as response vehicle. Discusses / compares energy use and performance with other vehicles based on manufacturer specifications.	Vehicle more efficient, some reduction in capacity (payload, horsepower) but not enough to prohibit its use.	Single experience; could be biased as author is an acknowledged environmentalist. Results based on manufacturer specifications rather than actual data collection.

Health Services							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
SDC-SEI	2008	Research	U.K.	Detail complete life cycle emissions arising from NHS England activities.	Prospective: Hybrid top-down approach. Input-output analysis applied to energy use in buildings and procurements, supplemented from U.K. Environmental Accounts and national travel survey for 2004.	Total emissions 21.3 million t CO_2e; indirect emissions from procurements account for 62%. Largest contributor is pharmaceuticals (21%).	Most extensive assessment of emissions in health setting. Use of U.K. I-O tables and Environmental Accounts assumes England is same as whole of U.K. (probably safe). Some risk of double-counting.
Chung & Meltzer	2009	Research	U.S.	Determine life cycle emissions from U.S. health sector	Retrospective: Top-Down. Used Carnegie-Mellon ‘EIO-LCA' tool to multiply previously published estimates of U.S. health spending by emission coefficients for health activities based on I-O analysis.	Total emissions were 545.54 million t CO_2e; indirect emissions accounted for 53% of emissions.	Source for expenditures could be flawed; use of pure I-O approach assumes all expenditure activities have same emissions profile.
SDU	2010	Summary	U.K.	Update NHS England carbon footprint.	Prospective: Calculate NHS London emissions using most recent data.	2007 emissions calculated as 21 million t CO_2e.	Methodology, data sources and explicit results not reported; this is a summary document.
Brockway	2010	Duplicate Pub.	U.K.	Report results of the two efforts above.	Re-iterates findings of original study and update in scientific/professional journal.	See above.	This is re-iteration of previously reported information.

Surgery

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Gilliam, Davidson & Guest	2008	Research	U.K.	Calculate the carbon footprint of CO_2 gas used during laparoscopic surgery.	Retrospective: Determined number of CO_2 cylinders used for laparoscopic surgery over 2.5 years.	415 C-sized cylinders used × ~0.9kg CO_2e per cylinder. Conclude emissions from laparoscopic surgery insignificant.	Direct emissions only. Does not include life cycle emissions associated with producing / bottling / distributing the gas, or other aspects of the surgeries.
Somner et al	2009	Research	U.K.	Compare the environmental impact of different approaches and different techniques of cataract surgery.	Prospective: Compared 'business as usual' 5-visit phacoemulsification technique to single-visit modified small incision (phacosection) cataract surgery (only one of each). Measured waste produced and electricity consumed. Used average distance travelled by 50 patients and European Commission vehicle emission target of 140g/km to estimate CO_2 emissions.	Single-visit phacosection technique could save 29.8 kg CO_2 per procedure, as well as 280 g of plastic and 8 g of paper.	Single centre, could be bias introduced by author; only one procedure of each type studied. Emissions calculate/estimated based on average patient travel and European Commission emission target for vehicles, not actual patient info (likely underestimates those emissions).

Surgery (continued)							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Gatenby	2011	Research	U.K.	"…examines the difference in carbon footprint between the surgical and medical treatment of gastro-oesophageal reflux".	Retrospective: Top-down. Applied NHS emission per £ expenditure (0.53kg – 0.56kg/ £) to cost for medical (n=164) or surgical (n=154) treatment plus ongoing medication costs based on costs reported in a previous cost-effectiveness comparison of the two approaches.	Initial emissions: 1007.5 kg CO_2e for surgery vs. 147.4 kg CO_2e for medical; ongoing emissions 30.8kg CO_2e/year surgery vs. 100 kg CO_2e/year medical. Estimated break even at 9th year.	Because of top-down approach, assumes uniform emissions per £ expenditure for all costs except medications (minor issue).
Ryan & Nielsen	2010	Research	U.S., Norway	Derive global warming potentials for common anaesthetic gases and then apply them to clinical scenarios.	Prospective: Bench study using infrared spectrometry to determine atmospheric lifetimes and radiative forcing of 3 anaesthetic gases, from which 20 year global warming potentials were calculated. Then calculated CO_2e emissions that would result from 1 hour operation using each of the gases in various clinical scenarios.	Global warming potential of sevoflurane was lowest, isoflurane was middle, desaflurane was highest. Because isoflurane can sometimes be used at lower flow rates than sevoflurane, CO_2e emissions using that gas could (sometimes) be lower with the same anaesthetic effect. Desaflurane emissions were much higher regardless of flow rate.	At any flow rate emissions from these gases are small, measured in grams per hour. Not able to judge the bench work to determine the global warming potentials. Emissions estimates are extrapolations; ignores life cycle emissions associated with producing, bottling and distributing the gas, as well as other emissions associated with the surgeries.

Surgery (continued)

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Bayazit & Sparrow	2010	Research	U.S.	Compare the energy-utilisation efficiency of conductive and convective patient warming devices.	Bench study: Two different convective devices and two different conductive devices were set up with heat sink to simulate patient. Measured energy consumption as well as heat lost to atmosphere (which would add to the air conditioning burden in a real operating room).	No clear advantage to either type of device; one brand of conductive device performed better than all others (~30% efficiency vs. ~5-15%). Appears to be more an issue with individual device characteristics than conductive vs. convective heating.	Small bench study with only 4 devices, each tested only once.

Dialysis							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Connor & Mortimer	2010	Research	U.K.	Establish a baseline measure of energy use in kidney care.	Prospective: Survey of 28 renal units about practices / perceptions / policies regarding building energy use, lighting, heating, equipment, travel, water use, supply consumption.	58 responses. Long list of activities / policies and percent of respondents having each. Notably, two facilities recapture reject water; nine have water saving taps.	Actual energy or water consumption not reported; emissions not estimated.
Tarrass, Benjelloun & Benjoelloun	2008	Research	Spain, Morocco	Evaluate the technologic and economic feasibility of recycling dialysis reject water for gray-water uses.	Prospective: Bench study. 500 mL samples of reject water collected from single dialysis centre. Physical and microbiologic analyses conducted. Compared cost of further treating reject water through filtering or reverse osmosis to that of reverse osmosis of sea water.	Reject water more conductive than other waste or municipal water, but otherwise similar to WHO/FAO standards for irrigation uses. Cost of further treatment using filtering or reverse osmosis less than cost of most methods of reverse osmosis of sea water.	Unclear how many samples were tested; cost estimates might be based on inaccurate assumptions (cannot judge).

Dialysis (continued)

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Agar et al	2009	Research	Australia	Review water use practices in a dialysis centre.	Prospective: Measured gross water use and reject water produced for conventional dialysis and home dialysis, assessed water quality, and described water conserving practices.	Including priming and rinse cycles, conventional dialysis uses 490 L per treatment; home dialysis uses 801 L per treatment. Reject water found to meet WHO guidelines for potable water. Flow restrictors reduce water consumption by 37.5%.	This appears to be data reported to prove a point: that use of reject water is feasible and safe. Only measured water consumption of a single machine in each setting (conventional vs. home), probably only once.
Agar	2010	Research	Australia	Confirm reject water is truly potable, and explore the potential for solar power home dialysis installations	Prospective: Biochemical and bacteriologic analysis of post-osmosis reject water from a single 16-station dialysis centre; measurement of power draw a single dialysis machine.	Reject water treated by reverse osmosis met EPA water quality criteria for potable water; 20kWh solar array could power home dialysis and produce excess power to be ‘sold back’ to the grid, return on investment would take 15 years.	Unclear how much of these data are new or repeated from above. All modelling / extrapolations seem to be based on single sample or single device. Cost effectiveness of solar determined for one machine only, and assumes private generators are compensated by energy suppliers for excess production.

Surgical Scrubbing							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Somner et al	2008	Research	U.K.	Investigate how much water is consumed in surgical scrubbing, and evaluate whether 'environmentally friendly' scrubbing behaviour leads to less water and energy consumption.	Prospective: Observed 25 separate scrubs at 2 locations with different kinds of sink taps; timed using a stopwatch. Multiplied scrub time × flow rate (75mL/s) to calculate water consumption; also calculated energy required to heat that volume of water from 13^{o}C to 38^{o}C.	At the hospital with knee-controlled taps, calculated water consumption was 5.7 L per scrub less than at the hospital with elbow controlled taps. Each scrub required 0.17kWh of energy to heat the water.	A small study but elegantly demonstrates that small things can reduce water consumption (and implicitly, energy consumption). Actual impact is likely underestimated (as discussed by the authors).
Jones	2009	Research	Australia	Determine how much water could be saved by using water-sparing practices during surgical scrubbing.	Prospective: Investigator performed a standardised 5 minute scrubbing routine using five scenarios: elbow-controlled high-flow tap; elbow-controlled low-flow tap; spring loaded foot pedal-controlled tap; motion sensor tap running continuously; motion sensor tap running intermittently. Water collected and measured.	Foot pedal control had lowest volume (6.7 L); high-flow elbow-controlled was worst (51.1 L).	Small study, potential bias as investigator performed the scrubs himself. But still show that when multiplied by all surgical scrubs done in a day/year/etc the volume of water that can potentially be saved is substantial.

Hospitals							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Gaglia et al	2007	Research	Greece	Use available data on existing building stocks to determine energy consumption and evaluate conservation measures.	Probably Retrospective: Methods not detailed. Appears to be part of larger government initiative on energy efficiency of buildings. Hospitals included as one subset of non-residential building stock.	Health buildings have the highest energy consumption per unit floor area compared to other non-residential buildings.	Despite lack of methodological detail, much data presented and likely sound. Hospitals / health buildings reported only as a subset of non-residential buildings, not specifically evaluated otherwise.
Murray, Pahl & Burek	2008	Research	U.K.	Describe energy consumption of small health clinics in Scotland.	Prospective: Hybrid. Random sample of NHS Scotland ‘C5' buildings; determined floor area and heated volume; conducted audit of energy consumption for 1 year. Calculated emissions using Department of Environment conversion factors.	Energy consumption totalled 310 kWh / m^2; (239 heating; 71 electricity). Emissions totalled 86 kg CO_2 / m^2.	Single year, small buildings only. Assumes emissions per unit of electricity and heat generation are the same at all sites. Otherwise methodologically sound.

Hospitals (continued)

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Bujak	2010	Research	Poland	Determine energy demand for hot water in hospitals, and explore seasonality of demand.	Prospective: Boiler control systems measured energy consumption and outside air temperature in two hospitals over 4 years; differentiated energy for central heating, hot water, and steam.	Energy for hot water production was relatively stable throughout the year, but varied greatly through course of individual days. Total average annual energy consumption 268 – 327 kWh/m^2. Hot water ~ 18 to 24% of energy consumption.	Excludes energy for lighting, medical equipment, etc. Only two hospitals.
Chirarattananon et al	2010	Advocacy	Thailand	Describe development of new building codes for large and very large buildings.	As part of developing new codes, an energy audit of existing buildings was undertaken using data in Department for Alternative Energy database.	79 hospitals averaged 148.8 kWh/m^2 energy consumption.	This is an incidental reporting of data; main point of the paper is to discuss new building codes and how they are implemented to improve energy efficiency in Thailand.

Hospitals (continued)

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Saidur et al	2010	Research	Malaysia	Analyse energy use in a public hospital, and evaluate energy savings and emissions reductions that could be achieved by using variable speed and/or high efficiency electric motors on equipment.	Ambispective: "Walk through energy audit" to identify equipment and types of motors; energy consumption taken from monthly bills for 1 year. Potential savings from variable speed / high efficiency motors estimated using mathematic formulations.	Energy intensity was 234 kWh/m^2. Lighting (36%) and medical equipment (34%) accounted for most energy consumption. Using high efficiency / variable speed motors could reduce energy consumption would reduce energy consumption and emissions ~20% to 60% depending on load factor and speed reduction.	Total energy consumption incidental finding of this study. Single hospital; more focused on electric motor efficiency and how that could impact energy consumption.
Lomas & Ji	2009	Research	U.K.	As part of multiple modelling experiments to assess the utility of passive ventilation systems in hospitals, "ascertain whether [advanced natural ventilation (ANV)] will contribute to mitigating climate change and helping the NHS meet it energy demand targets…".	Ambispective: Using historic temperature data and characteristics of an ANV ventilated ward room, modelled energy consumption / emissions for ANV vs. conventional ventilation systems.	Modelled emissions ranged from 48 kg CO_2e / m^2 to 171 kg CO_2e / m^2 depending on ventilation system characteristics, with passive systems having lower emissions than conventional systems.	Small part of much larger work. Modelled rather than actual energy consumption / emissions, based on a 'typical' ward room.

Hospitals (continued)

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Renedo et al	2006	Research	Spain	To determine the optimal on-site cogeneration configuration for a single hospital.	Ambispective: Using current hospital energy consumption as a reference scenario, modelled ability of cogeneration with diesel generators or gas turbines, with and without producing electricity from any excess capacity of the generators.	All scenarios found to be effective, with no major differences in cost effectiveness; depends on ability to sell excess electricity production back to grid. As part of reference scenario reports electricity consumption (13.535 mWh) and thermal energy consumption (26,000 mWh) per year; buildings total 80,000 m^2.	Somewhat confusing reporting of baseline scenario – not the main point of the paper.

Clinical Trials

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Burnett et al	2007	Research	U.K., 49 countries	"A carbon audit of the CRASH Trial".	Retrospective: Bottom-up / hybrid estimates of fuel/energy consumption and waste disposal of coordinating centre, staff travel, and distribution of study materials.	126t/ CO_2e for 1 year; extrapolated to 630t for whole study, or 63kg per participant	Reasonable attempt at Scope 3 accounting; some omissions. Raises point that clinical studies have external impacts.

Telemedicine

Author	Year	Type	Country	Aim	Methods	Findings	Comment
Smith, Patterson & Scott	2007	Advocacy	U.K., Canada, Australia	Report three examples of "how doctors can reduce their carbon footprint using telemedicine".	Letter summarising authors' experiences and one additional (unreferenced) study.	Telemedicine reduces patient and practitioner travel, which reduces fuel consumption and therefore emissions.	This is a letter in BMJ. Data are presented from a Canadian study but it is not referenced. Data from an Australian study are cited but only the abstract of that paper could be obtained. A paper from the U.K. (authored by a co-author of this letter) is cited but the data reported in this letter are not present in that original paper.
Yellowlees et al	2010	Advocacy	U.S.	Review "…possible options for the American health industry to become greener…"	Extrapolation of travel savings per telemedicine consultation versus in-person consultation.	Savings of 188,000 gallons (714,000 L) of petrol and 1,700 t CO_2 (131 kg / consultation).	No description of how data were acquired or how the calculations were made, and there is no citation of a primary source.

Meetings

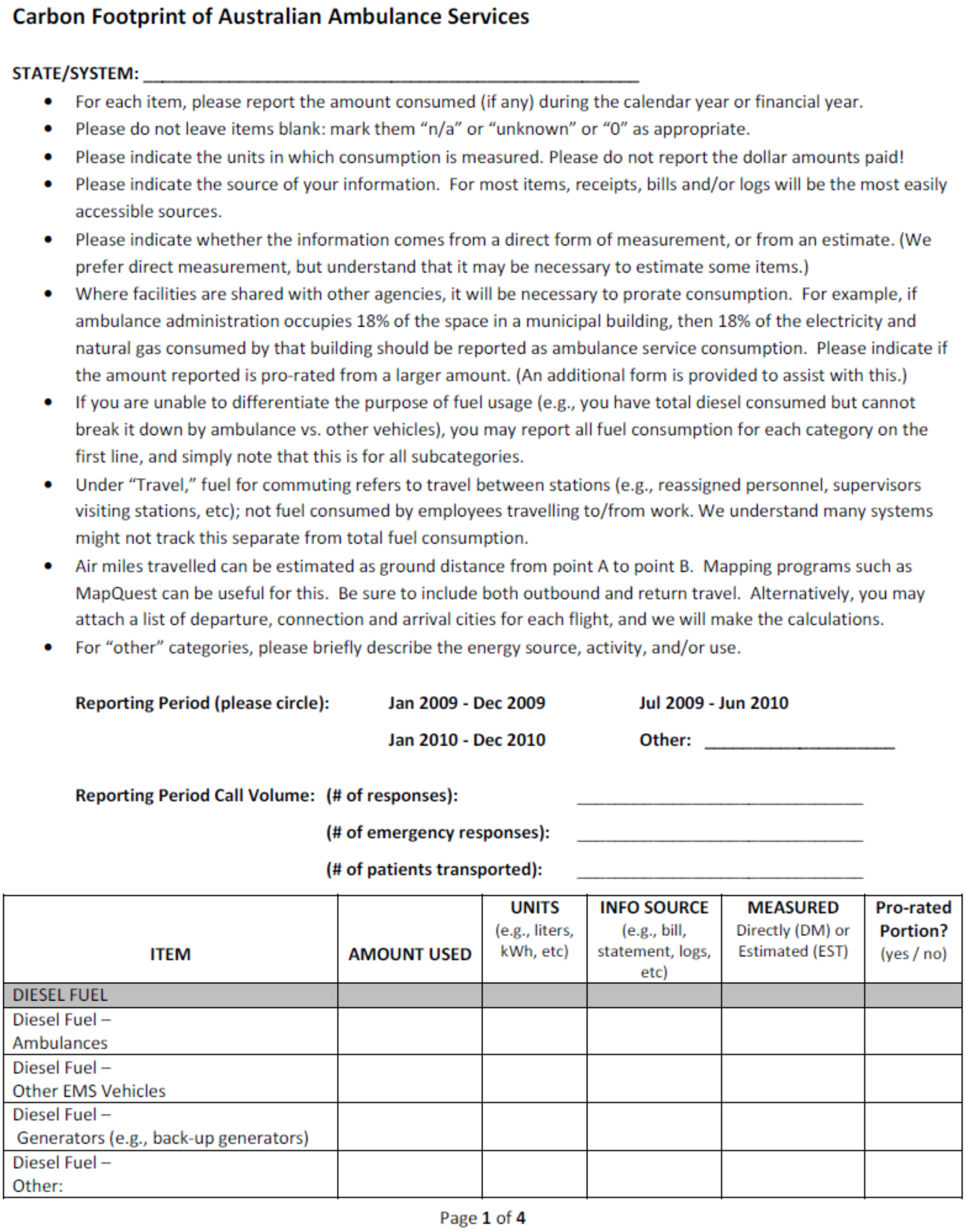
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Callister & Griffiths	2007	Advocacy	U.S., U.K.	Estimate emissions associated with American Thoracic Society meeting.	Letter: Used distance from largest city in delegates' home state to conference site, and emission multipliers for Boeing 737 (for trips less than 2000 km) or Boeing 747 (for trips greater than 2000 km). Calculated total travel related emissions for various cities that had hosted the meeting.	Estimated travel related emissions for 2006 San Diego meeting were 10,779 t CO_2e. For other cities emissions ranged between 7,813 t to 10,870 t.	Assumptions about travel distances and type of aircraft likely flawed. Some participants would drive. Does not include other aspects of the even (building use of electricity, paper/plastic products, etc).
Hudson	2008	Advocacy	New Zealand	Estimate emissions related to travel to Australian & New Zealand college of surgeons meeting in Hong Kong.	Letter: Uses 110 g of CO_2 per passenger kilometre to estimate emissions from a single participant flying from Sydney to Hong Kong return.	A single participant flying from Sydney to Hong Kong. return would be responsible for 1.6 t CO_2, and 4.3 t CO_2e	Participants would travel from other cities; no mention of number of participants.
Crane & Caldwell	2006	Advocacy	New Zealand	Estimate emissions associated with attendance at European Respiratory Society meeting in Munich.	Used home country data from meeting website to estimate travel related emissions for all participants; also estimated paper consumption to produce conference proceedings.	17,240 participants' travel estimated to emit 3,920 t CO_2e, plus 36.2 t of paper used.	No clear description of how travel distances/modes were determined or allocated; uses same multiplier for all air trips (independent of type of aircraft).

Specialty Training							
Author	Year	Type	Country	Aim	Methods	Findings	Comment
Hewitt	2008	Advocacy	U.K.	Describe carbon footprint of process of applying for specialty training placements for one individual.	Anecdote: Estimated paper use, printer ink consumption, electricity to power computers, transport of forms by post office / couriers; used online calculator to determine carbon footprint.	480 kg CO_2e.	Energy consumption / transport not specifically measured; use of calculator assumes emission intensity of her activity / consumption is the same as national average. Single experience.

Appendix 6 Abbreviations

£	British Pounds
ANV	advanced natural ventilation
BMJ	British Medical Journal
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
EIA	Energy Information Administration
EIO-LCA	Environmental Input-Output—Life Cycle Assessment
EMS	emergency medical services
EPA	Environmental Protection Agency
g	grams
I-O	Input-Output
kg	kilograms (1,000 grams)
km	kilometres
kWh	kilowatt hours
L	litres (1,000 mL)
m^2	square metres
mL	millilitres
mWh	megawhatt hours (1,000 kWh)
NHS	National Health Service
SDC	Sustainable Development Commission
SEI	Stockholm Environment Institute
t	metric tonnes (1,000 kg)
U.K.	United Kingdom
U.S.	United States
WHO	World Health Organisation

Appendix 7: Data collection tool and pro-rating worksheet for the study of Australian Scope 1 and Scope 2 energy consumption and greenhouse gas emissions (Chapter 4).



Carbon Footprint of Australian Ambulance Services

STATE/SYSTEM: ____

- For each item, please report the amount consumed (if any) during the calendar year or financial year.
- Please do not leave items blank: mark them "n/a" or "unknown" or "0" as appropriate.
- Please indicate the units in which consumption is measured. Please do not report the dollar amounts paid!
- Please indicate the source of your information. For most items, receipts, bills and/or logs will be the most easily accessible sources.
- Please indicate whether the information comes from a direct form of measurement, or from an estimate. (We prefer direct measurement, but understand that it may be necessary to estimate some items.)
- Where facilities are shared with other agencies, it will be necessary to prorate consumption. For example, if ambulance administration occupies 18% of the space in a municipal building, then 18% of the electricity and natural gas consumed by that building should be reported as ambulance service consumption. Please indicate if the amount reported is pro-rated from a larger amount. (An additional form is provided to assist with this.)
- If you are unable to differentiate the purpose of fuel usage (e.g., you have total diesel consumed but cannot break it down by ambulance vs. other vehicles), you may report all fuel consumption for each category on the first line, and simply note that this is for all subcategories.
- Under "Travel," fuel for commuting refers to travel between stations (e.g., reassigned personnel, supervisors visiting stations, etc); not fuel consumed by employees travelling to/from work. We understand many systems might not track this separate from total fuel consumption.
- Air miles travelled can be estimated as ground distance from point A to point B. Mapping programs such as MapQuest can be useful for this. Be sure to include both outbound and return travel. Alternatively, you may attach a list of departure, connection and arrival cities for each flight, and we will make the calculations.
- For "other" categories, please briefly describe the energy source, activity, and/or use.

Reporting Period (please circle): **Jan 2009 - Dec 2009** **Jul 2009 - Jun 2010**
Jan 2010 - Dec 2010 **Other:** ____________________

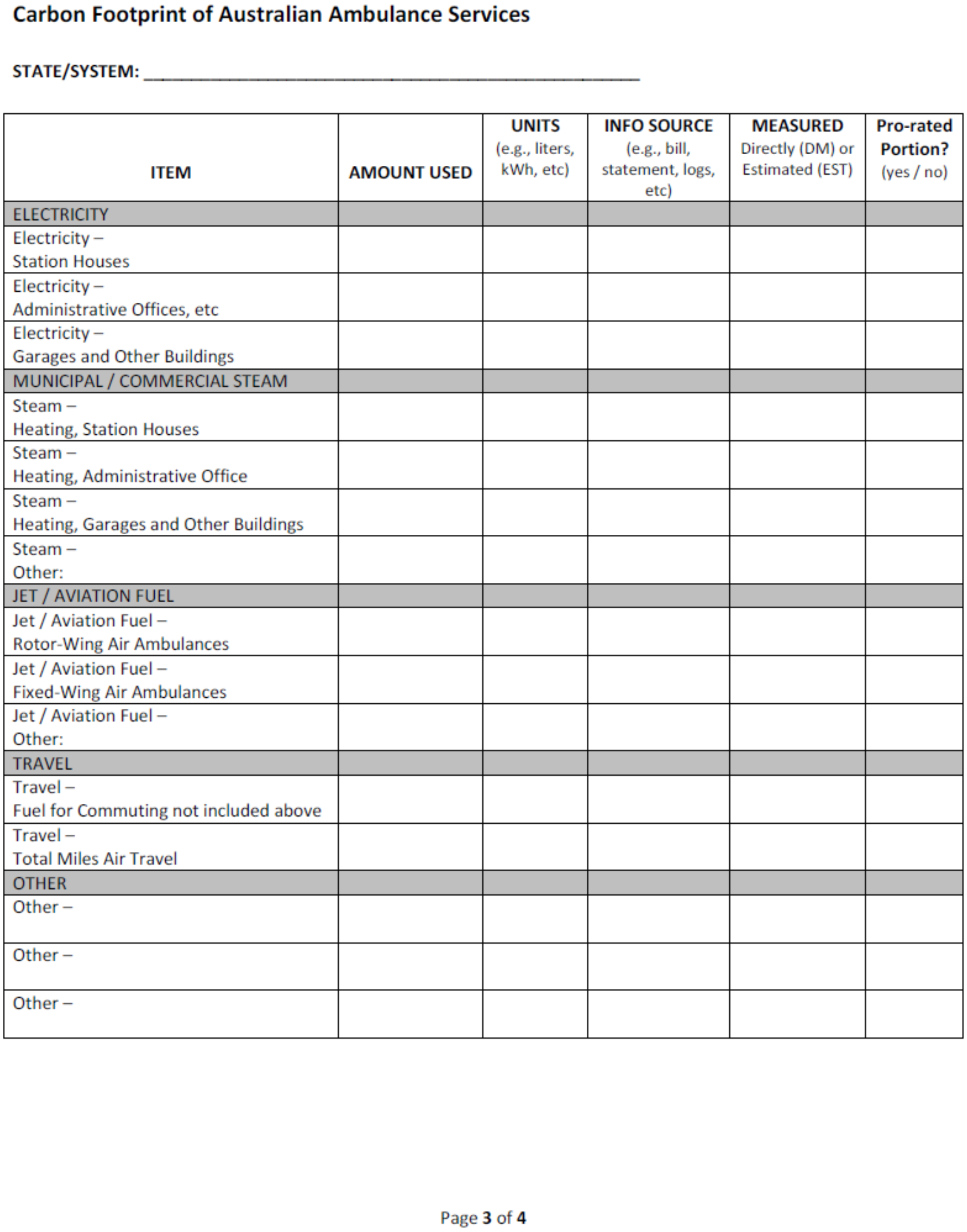
Reporting Period Call Volume: **(# of responses):** ____________________
(# of emergency responses): ____________________
(# of patients transported): ____________________

ITEM	AMOUNT USED	UNITS (e.g., liters, kWh, etc)	INFO SOURCE (e.g., bill, statement, logs, etc)	MEASURED Directly (DM) or Estimated (EST)	Pro-rated Portion? (yes / no)
DIESEL FUEL					
Diesel Fuel – Ambulances					
Diesel Fuel – Other EMS Vehicles					
Diesel Fuel – Generators (e.g., back-up generators)					
Diesel Fuel – Other:					

Carbon Footprint of Australian Ambulance Services

STATE/SYSTEM: ____

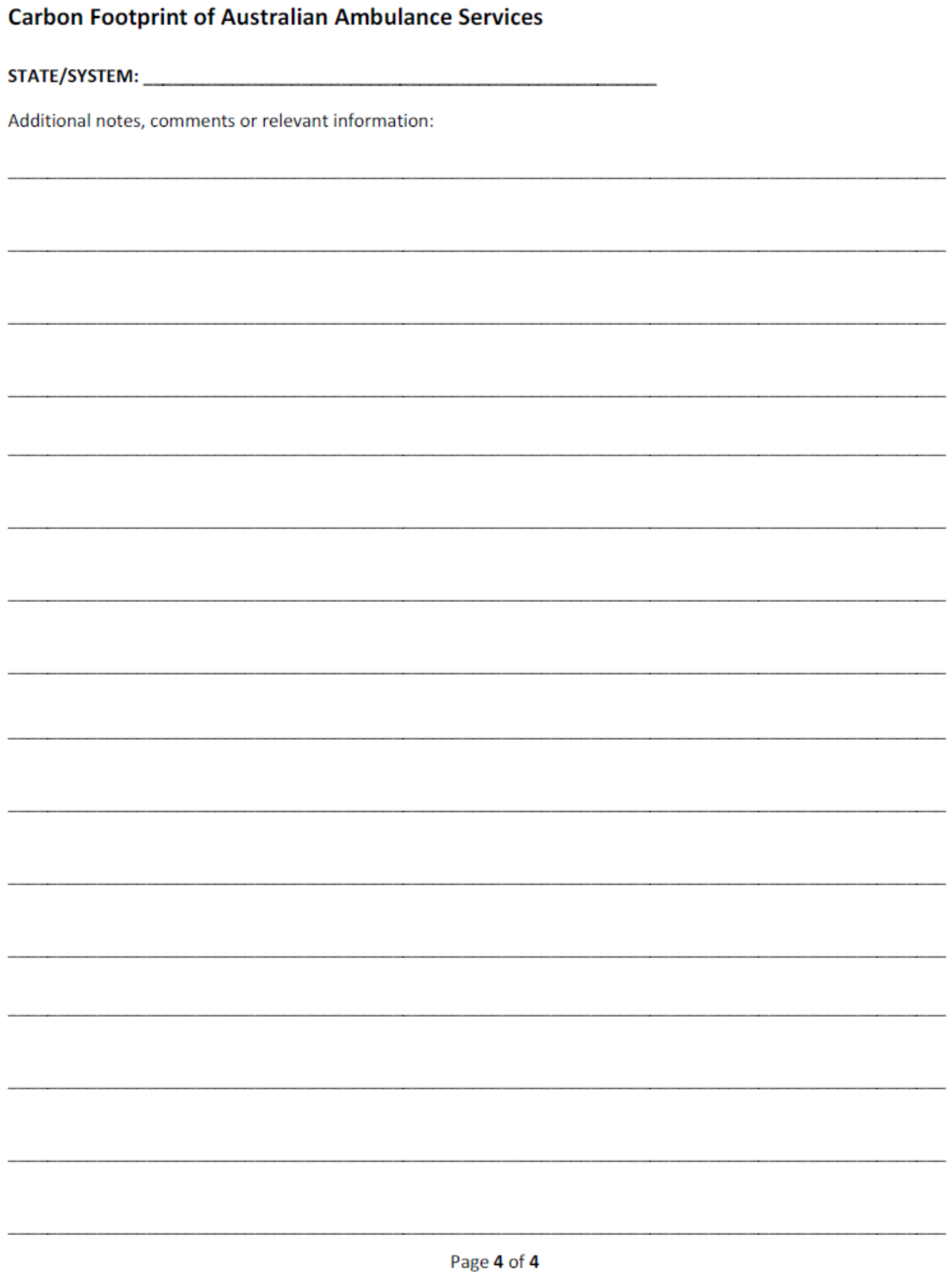
ITEM	**AMOUNT USED**	**UNITS** (e.g., liters, kWh, etc)	**INFO SOURCE** (e.g., bill, statement, logs, etc)	**MEASURED** Directly (DM) or Estimated (EST)	**Pro-rated Portion?** (yes / no)
PETROL					
Petrol – Ambulances					
Petrol – Other EMS Vehicles					
Petrol – Generators (including extrication tools)					
Petrol – Other:					
COMPRESSED NATURAL GAS (CNG)					
Compressed Natural Gas (CNG)– CNG for EMS Vehicles					
Compressed Natural Gas (CNG) – Other:					
NATURAL GAS					
Natural Gas – Heating, etc, Station Houses					
Natural Gas – Heating, etc, Administrative Office					
Natural Gas – Heating, etc, Garages / Other Buildings					
Natural Gas – Other:					
FUEL OIL					
Fuel Oil – Heating, etc, Station Houses					
Fuel Oil – Heating, etc, Administrative Office					
Fuel Oil – Heating, etc, Garages / Other Buildings					
Fuel Oil – Other:					
LIQUEFIED PETROLEUM (LP)					
Liquefied Petroleum – Generators					
Liquefied Petroleum – Other:					



Carbon Footprint of Australian Ambulance Services

STATE/SYSTEM: ____

ITEM	**AMOUNT USED**	**UNITS** (e.g., liters, kWh, etc)	**INFO SOURCE** (e.g., bill, statement, logs, etc)	**MEASURED** Directly (DM) or Estimated (EST)	**Pro-rated Portion?** (yes / no)
ELECTRICITY					
Electricity – Station Houses					
Electricity – Administrative Offices, etc					
Electricity – Garages and Other Buildings					
MUNICIPAL / COMMERCIAL STEAM					
Steam – Heating, Station Houses					
Steam – Heating, Administrative Office					
Steam – Heating, Garages and Other Buildings					
Steam – Other:					
JET / AVIATION FUEL					
Jet / Aviation Fuel – Rotor-Wing Air Ambulances					
Jet / Aviation Fuel – Fixed-Wing Air Ambulances					
Jet / Aviation Fuel – Other:					
TRAVEL					
Travel – Fuel for Commuting not included above					
Travel – Total Miles Air Travel					
OTHER					
Other –					
Other –					
Other –					



Carbon Footprint of Australian Ambulance Services

STATE/SYSTEM: ______________________________

Additional notes, comments or relevant information:

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Multiple Location Energy Consumption and Pro-Rating Template

Ambulance Service: ____

Energy Source: ____ (e.g.: electricity; natural gas; compressed natural gas; liquefied petroleum; etc)

Unit of Measure: ____ (e.g.: litres; cubic feet; therms; etc.)

This sheet is a template to help with collecting data from multiple locations and pro-rating of energy consumption where facilities or resources are shared by multiple agencies. To use this form, collect the meter readings or other record of amount consumed, provide an estimate of the percent of the facility or resource that is attributable to the ambulance service, and multiply that by the total consumption to fill in the last column. The totals from each sheet can then be added together and transferred to the primary data form. Alternatively, you may provide all of the pro-rating templates (with columns 1-5 & 7 completed) to the study investigators and we will do the calculations.

Location	Last 2009 Reading Date	Last Reading 2009	Last 2010 Reading Date	Last Reading 2010	Total Amount Consumed	Ambulance Service %	Ambulance Service Amount
					TOTAL		

(Use additional pages if needed, or if completing this form electronically you may insert additional rows.)