The Energy and Environmental Burden

of Australian Ambulance Services

Thesis submitted by

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Declaration on Ethics

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.

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*. Based on Chapter 4.

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.

Brown, L.H., Canyon, D.V., Buettner, P.G., Crawford, J.M., Judd, J. (Under Review). Estimating the complete life cycle emissions of Australian ambulance operations. Based on Chapter 5.

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.

Brown, L.H., Blanchard, I.E. (2012). Energy, emissions, and emergency medical services: Policy matters. *Energy Policy*, 46, 585-593. Portions of the discussion in Chapter 7 are adapted from this manuscript.

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, Annice, for wagging that finger up and down in front of my nose, and for working all of those shifts while I commuted to Greenville to take the paramedic course. That started this ball rolling so many years ago.

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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	90^{th} 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.