The Use of Carbon Footprinting Studies to Determine the Greenhouse Gas Emissions Associated with the Provision of Aspects of Renal Healthcare within the National Health Service.

by

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Declarations

I confirm that this thesis has not been submitted for any degree at another university.

The work contained within this thesis is my own except where outlined below.

In Chapter 2, the application of the principles of clinical transformation to the provision of renal services is illustrated using examples identified from the published medical literature. The concept for this chapter was developed by the author, who undertook the literature search and produced the initial drafts. In preparation for the publication of this work in a nephrology journal, these drafts were reviewed by Dr Frances Mortimer and Dr Charles Tomson, whose comments therefore informed the writing of both the published paper and the final version of the chapter by the author.

In Chapter 3, Dr Frances Mortimer contributed to the design of the questionnaire used to collect data on the sustainability of renal services across England, Scotland and Wales. The subsequent data collection, analysis and interpretation were undertaken by the author.

In Chapter 5, data regarding the electrical energy consumption of various dialysis machines was collected as part of the study to determine the carbon footprints of providing dialysis using differing machines and regimes. For standard haemodialysis machines, the collection of this data was undertaken by the author with the assistance of two renal technicians at the Dorset County Hospital (Fraser Gilmour and Ian Powell). The collection of this data for NxStage equipment was undertaken by Chris Bates (renal technician at the Lister Hospital, Stevenage) at the request of, and with guidance from, the author.

Chapter 6 reports a study in which the energy savings attributable to the use of heat exchangers on haemodialysis machines were quantified. Although the methods for this study were determined in consultation with the author of this thesis, the author played no part in the data collection process (which was primarily undertaken by Fraser Campbell, a renal technician at the Maidstone Dialysis Unit). The author of this thesis collaborated in the initial interpretation of the results, and was subsequently responsible for the writing up of the work (both in the form of a case study presented on the website of the Centre for Sustainable Healthcare and as an abstract presented in poster form at the British Renal Society/Renal Association Joint Meeting, Manchester, 2010).

Chapter 6 reports the use of telephone clinics to provide follow up for renal transplant recipients. The evaluation of the environmental benefits of this model required the collection of patient travel data. The collection of the required data was undertaken by Dr Rob Higgins under guidance from the author.

Chapter 6 reports the salvage of reject water during the provision of haemodialysis. The data used to determine the volumes of water conserved were provided by Steve Milne, a renal technician at the Canterbury renal unit.

Prior Publications

Parts of this thesis have been previously been published in condensed form as detailed below:

Connor A, Lillywhite R, Cooke MW. The carbon footprint of a renal service in the United Kingdom. *Quarterly Journal of Medicine*, 103(12):965-975, 2010.

Connor A, Lillywhite R, Cooke MW. The Carbon Footprints of Home and In-centre Maintenance Hemodialysis in the UK. *Hemodialysis International,* Jan 14th 2011. doi: 10.1111/j.1542-4758.2010.00523.x [Epub ahead of print].

Connor A, Milne S, Owen A, Boyle G, Mortimer F, Stevens PE. Towards Greener Dialysis: A Case Study to Illustrate and Encourage the Salvage of Reject Water. *Journal of Renal Care,* 36(2):68-72, 2010.

Connor A, Mortimer F. The green nephrology survey of sustainability in renal units in England, Scotland and wales. *Journal of Renal Care,* 36(3):153-160, 2010.

Connor A, Mortimer F, Higgins R. The Follow Up of Renal Transplant Recipients by Telephone Consultation: Three Years Experience from a Single UK Renal Unit. *Clinical Medicine*, 11(3):242–246, 2011.

Connor A, Mortimer F, Tomson C. Clinical Transformation – the Key to Green Nephrology. *Nephron Clinical Practice*, 116:200–206, 2010.

Connor A, Thomson M, Mortimer F. Green Waste Management for Renal Medicine Units. *British Journal of Renal Medicine*, 15(2):7-11, 2010.

Campbell F, Milne S, Connor A, Stevens P. P195 Heat exchangers in haemodialysis machines achieve significant environmental and cost savings. UK British Renal Society/Renal Association Joint Meeting, Manchester, May 2010. Available at: http://www.britishrenal.org/Conferences/Conferences-Home/2010Conference/Poster-Programme.aspx (Last accessed 23rd July 2010).

Abstract

Climate change presents a major threat to global health and will further exacerbate the health inequalities that exist internationally. However, the provision of healthcare results in considerable greenhouse gas (GHG) emissions and is therefore contributing to climate change itself. Meanwhile, the integration of strategies to address climate change into global health efforts will realise health co-benefits. Meeting the challenging carbon reduction targets set within the NHS will require an improved understanding of the GHG emissions association with different forms of healthcare. This thesis explores the environmental impact of the provision of renal medicine services within the United Kingdom, placing a particular emphasis upon GHG emissions.

The approach required, and the opportunities that exist, to reduce the environmental impact of renal medicine services are first explored through a review of the existing literature and a survey of the current practices of renal services in England, Scotland and Wales. A study, adhering to the principles of PAS2050, of the GHG emissions attributable to an individual renal service is then reported. This is the first assessment of the carbon footprint of an individual specialty service to include both direct and indirect GHG emissions. Consideration is given to how the results might inform carbon reduction strategies. Indicative carbon burdens for outpatient appointments and inpatient admissions are derived in order to facilitate future modelling of the emissions attributable to different clinical pathways of care. A second study, in which the GHG emissions attributable to different forms of an individual treatment (haemodialysis) are determined, is then presented. Finally, four case studies of good environmental practice within renal medicine, identified from the earlier literature search and survey, are presented in the context of the results of these studies.

Abbreviations

CH_4	Methane
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
DCH	Dorset County Hospital
DEFRA	Department for Environment, Food and Rural Affairs
ERIC	Estates Return Information Collection
eGFR	estimated Glomerular Filtration Rate
EIO-LCA	Environmental Input-Output, Life-Cycle Assessment
ESRD	End-stage Renal Disease
g	Gram(s)
GHG	Greenhouse Gas(es)
HHD	Home Haemodialysis
ICE	Inventory of Carbon and Energy
ICHD	In-centre Haemodialysis
J	Joules
K	Degrees Kelvin
kg	Kilogram(s)
Km	Kilometre(s)
kWh	Kilowatt Hours
LCA	Life-Cycle Assessment
$ml/min/1.73m^2$	Millitres per minute per 1.73 square metres
N_2O	Nitrous Oxide
NHS	National Health Service
OECD	Organisation for Economic Co-operation and Development
PAS2050	Publically Available Standard 2050
PCT	Primary Care Trust
PbR	Payment by Results

PGH	Poole General Hospital
RBH	Royal Bournemouth Hospital
RRT	Renal Replacement Therapy
SMH	Southmead Hospital
UHCW	University Hospital of Coventry & Warwickshire
YDH	Yeovil District Hospital

Chapter 1.

Climate Change, Health and Healthcare. An Introduction to the Thesis.

Introduction

This thesis explores the environmental impact of the provision of renal medicine services within the United Kingdom. A particular emphasis is placed upon the emission of greenhouse gases (GHG) in recognition of the current consensus amongst the international scientific community that GHGs are contributing to climate change [Intergovernmental Panel on Climate Change, 2007].

This thesis does not explore the relationship between GHGs and climate change. However, an overview of the relationships that may exist between GHG emissions (and, therefore, climate change), global health, and the provision of healthcare is provided within this introductory chapter in order to contextualise the carbon footprinting studies and other assessments that are described in the subsequent chapters.

Climate Change

Through global population growth and intensified economic activities, the actions of humans are increasingly impacting upon the world's biophysical and ecological systems and resulting in environmental changes such as freshwater shortages, loss of biodiversity, depleted material resources and the exhaustion of fisheries. Climate change may represent a further such example.

The earth's atmosphere contains GHGs, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour. The 'greenhouse effect' describes the process by which the selective absorptive properties of these gases attenuate the energy losses from the earth and contribute to ensuring that the earth's surface is hospitable to life [Serreze, 2010]. The magnitude of this greenhouse effect is believed to be changing.

Since the industrial revolution, the combustion of fossil fuels, which were formed hundreds of millions of years ago, has released CO_2 back into the atmosphere. Atmospheric levels of CO_2 had risen to a level of 383 parts per million by 2007, more than 100 parts per million greater than at the time that James Watt patented the steam engine in 1769 [Rogner et al., 2007]. Furthermore, the levels of other GHGs are also increasing, giving a 'carbon dioxide equivalent' (CO_2eq) level of 455 parts per million [Rogner et al., 2007]. Anthropogenic GHG emissions (those originating from the activities of human beings) increased by 70% over the last three decades of the 20^{th} century, such that by 2004 these emissions had reached 49 billion tonnes CO_2eq [Rogner et al., 2007]. Furthermore, every one of the thirteen years between 1997 and 2009 was amongst the fourteen warmest years on record since 1880 [National Oceanic and Atmospheric Administration, 2010]. The rising global mean annual surface air temperature is accompanied by thawing of the permafrosts, glacial and ice sheet mass reductions, a decline in the amount of floating sea ice, and rising sea levels [Serreze, 2010]. Indeed, there is now a clear consensus amongst international scientists that the rising levels of man-made atmospheric GHGs are potentiating the greenhouse effect and represent the predominant driver of global climate change [Intergovernmental Panel on Climate Change, 2007].

Climate Change and Global Health

The relationship between climate change and global health is complex and not yet fully understood [Frumkin et al., 2008; Global Humanitarian Forum, 2009]. Climate change threatens the stability, productivity, and resilience of the natural environment upon which human biology and ecology depend, and therefore represents a direct threat to population health [McMichael et al., 2009]. Further potential indirect threats to global health might result from the impact of climate change upon livelihoods, wellbeing, economic productivity, and social stability within populations. However, whilst it is therefore apparent that the effects of climate change will impact adversely upon global health, it is also clear that many of the causes of poor health are themselves also contributing to climate change.

The Impact of Climate Change upon Global Health

It is now appreciated that climate change presents a major threat to global health [Costello et al., 2009; Global Humanitarian Forum, 2009]. Altered patterns of disease and mortality will result from food and water insecurity, extreme climatic events (such as flooding, heat waves, wildfires, earthquakes and tornados) and changes in the nature and distribution of transmissible diseases [Costello et al., 2009; Nichols et al., 2009]. Vulnerable human settlements will suffer directly, whilst the resulting population migration will ensure that few regions of the globe are unaffected. It has been suggested that these stresses may also result in conflict including war [Costello et al., 2009; Jarvis et al., 2011].

Furthermore, the effects of anthropogenic climate change upon health will not be distributed uniformly around the globe [Campbell-Lendrum & Woodruff, 2006]. The greatest health impacts will be felt by those who have contributed the least to the accumulated reservoir of GHG emissions, and for whom access to healthcare resources is most limited [McMichael et al., 2004; Global Humanitarian Forum, 2009], further exacerbating the health inequalities that exist at a global level between the rich and poor [Costello et al., 2009].

The Problems of Global Health and Climate Change share some Common Origins

Whilst the most devastating health impacts of climate change are yet to be realised [Costello et al., 2009], some of the factors contributing to rising anthropogenic GHG emissions are also contributing to many of the more immediate public health challenges, including the epidemics of obesity, hypertension and diabetes. Worldwide, obesity has more than doubled since 1980; over 1.5 billion adults are now overweight, of whom around 500 million meet the diagnostic criteria for obesity [World Health Organisation, 2011]. At least 2.8 million adults worldwide die each year as a result of being overweight or obese. In addition, 44% of the diabetes burden, 23% of the ischaemic heart disease burden and between 7% and 41% of certain cancer burdens are attributable to overweight and obesity [World Health Organisation, 2011].

Obesity most commonly results from an energy imbalance between calorie consumption and expenditure. The widespread availability of energy-dense foods which are high in salt, fat and sugars, and the increasingly sedentary nature of western lifestyles, are acting synergistically to encourage weight gain [Mozaffarian et al, 2011; Prentice & Jebb, 2004]. It has been argued that, in the United Kingdom at least, the reduction in physical activity is the more influential of these two factors, as the average recorded energy intake has fallen despite escalating levels of obesity [Prentice & Jebb, 1997]. The increasing motorisation of human movement, in place of active modes of travel such as cycling and walking, has been implicated as a major contributor to the reductions in physical activity; in an analysis of the populations of 130 countries, lower levels of motor vehicle gasoline consumption per capita were found to correlate with lower average body mass indices [Roberts & Edwards, 2010]. As motorised transport is almost entirely dependent on fossil fuels and accounts for almost half of all oil use worldwide it is not only driving the obesity epidemic but also contributing to climate change. Increasing the uptake of active travel methods must therefore be considered integral to strategies to tackle both the immediate public health challenges and the more distant health impacts of climate change [Woodcock et al., 2009].

Similarly, the increasingly sedentary nature of many forms of work has also reduced physical activity levels. Whilst the proportion of the workforce of the United Kingdom working within financial and business services (and undertaking, it might be assumed, relatively sedentary work) has been steadily rising, the proportion working within the agricultural sector (and undertaking physically demanding work) has been falling. Although around 77% of the total land area of the United Kingdom is now farmed [Ashton, 2002], the agricultural workforce now comprises only 0.5% of the total workforce in England [DEFRA, 2010]. This represents a fall of 12% since 2001. By contrast, in 1850 around 22% of the British workforce was in agriculture. The industrialisation of the agricultural sector (a process which, of course, has contributed to the widespread availability of energy-dense foods and is a major contributor to anthropogenic climate change [McMichael et al., 2007]) has not only resulted in a proportional reduction in the sector's workforce but also explains why those remaining in agriculture now undertake comparatively less physically demanding work. Similarly, the mechanisation of the construction and building industries, the replacement of labour-intensive steam power with diesel and petrol engines, and the use of labour saving devices in the home (for example, vacuum cleaners, washing machines, dishwashers, gas and oil fired heating systems in place of coal and wood fires) have all contributed to increasingly sedentary lifestyles. The recognition of the health benefits of increasing physical activity in the workplace [National Institute for Health and Clinical Excellence, 2008] offers an opportunity to reduce the associated GHG emissions, for example through active travel plans.

Livestock production is another major contributor to emissions of GHGs [McMichael et al., 2007; Steinfield et al., 2006] and a further example of the overlap with health. The annual GHG emissions arising from the consumption of a mixed meat and vegetable diet, with the mean American caloric content and composition, are almost 1.5 tonnes CO_2eq greater per person than the consumption of the same number of calories from plant sources [Eshel & Martin, 2006]. Meanwhile, diets lower in red meats are associated with health benefits including reduced risks of diabetes, cancer and ischaemic heart disease [Aune et al., 2009; World Cancer Fund, 2007; Larsson & Wolk, 2006; Sinha et al., 2009].

The magnitude, timeframe and geographical distribution of the obesity epidemic have, for some time now, been indicative that its primary vectors (the imbalance in calorie consumption and expenditure) have resulted from societal changes at a population level. Indeed, it has been suggested that a more enlightened health sector might have engaged at an early stage with those other sectors, such as those responsible for transport and food, with the capacity to influence these vectors [Egger et al., 2003]. The recognition of the significance of climate change, and its connections to global health, must now trigger effective collaboration amongst such sectors, such that population health is re-affirmed as an organising principle of sustainable development.

Climate Change and the Provision of Healthcare

Whilst it is therefore clear that, left unchecked, the impact of climate change upon global health may be considerable, it is also evident that the integration of strategies to address climate change into global health efforts will realise valuable health co-benefits. Additional reasons why the healthcare sector, and the specialty of renal medicine, should implement strategies to reduce its GHG emissions include: the legally binding targets introduced by the Government through the Climate Change Act of 2008 [National Archives, 2008(a)]; the possibilities for financial savings, initially primarily through increased energy efficiency, at a time of unprecedented reductions in the resources available to the National Health Service (NHS) [Audit Commission, 2010]; and the need, and opportunity, for NHS organisations and professionals to set an example [Royal College of Physicians, 2010; Roberts, 2009].

However, the integration of strategies to address climate change within global health activities must begin with the consideration of the delivery of healthcare itself - as this results in the release of GHG, thereby directly contributing to climate change and its attendant threat to global health [Sustainable Development Commission, 2008; Chung & Meltzer, 2009; Lyle et al, 2009]. Indeed, the magnitude of this contribution is considerable. The NHS England Carbon Emissions Carbon Footprinting Report concluded that the GHG emissions attributable to the NHS in England alone represent 25% of the carbon footprint of the public sector of the United Kingdom [Sustainable Development Commission, 2008].

The Challenge Facing the NHS

Informed by the NHS England Carbon Emissions Carbon Footprinting Report, the NHS Carbon Reduction Strategy has set targets for the reduction of GHG emissions within the NHS [NHS Sustainable Development Unit, 2009]. Taking 2007 levels as the baseline, the strategy requires an 80% reduction before 2050 and a 34% reduction as early as 2020. These are challenging targets which will only be achieved by fully understanding the GHG emissions associated with the delivery of healthcare.

An Outline of this Thesis

Human activity, including the provision of healthcare, has many consequences for the Earth's physical and biological systems. This thesis explores the environmental impact of the specialty of renal medicine and begins to identify strategies to reduce it. In recognition of the particularly urgent nature of the threat to global health posed by climate change, the thesis focuses upon the GHG emissions arising from the provision of renal services, although examples of the wider environmental consequences (such as the consumption of water and of non-renewable resources, environmental pollution and impacts on biodiversity) of these services are also identified. For the benefit of non-physicians, Appendix 1 describes the nature of renal services within the United Kingdom, focusing upon those aspects of service provision which are of particular relevance to this thesis.

Chapter 2 considers the approach required to reduce the GHG emissions of renal services in the United Kingdom. It concludes that improvements in energy efficiency alone will not be sufficient, and that a transformation of the way in which renal services are provided will be required. The principles that might underpin such a clinical transformation are illustrated using examples of good environmental practice identified through a search of the medical literature.

Chapter 3 considers the extent to which these strategies are already incorporated into the delivery of the renal services of England, Scotland and Wales. Further examples of good environmental practice are identified, as well as opportunities for improvements. This chapter draws upon the responses of 58 renal services to a wide-ranging and in-depth survey of sustainability, designed to identify strategies for improvement across the different areas of renal services, including building energy use, patient and staff travel, the procurement of resources and consumable goods, and waste management strategies.

Having identified, in the preceding two chapters, opportunities to reduce the GHG emissions associated with renal services from both the medical literature and existing practice, Chapter 4 seeks to contextualise these opportunities through the description of a study of the GHG emissions attributable to an individual renal service within the United Kingdom. This study represents the first assessment of the carbon footprint of an individual specialty service to include both direct and indirect emissions. The chapter considers the overall emissions attributable to the service, and also how knowledge of the contributions made by the different sectors (including building energy use, travel, procurement and waste management) can inform carbon reduction strategies. Indicative carbon burdens for two individual healthcare activities, the provision of outpatient appointments and inpatient admissions, are derived in order to facilitate future modelling of the emissions attributable to different clinical pathways of care.

This description of the carbon footprint of a healthcare service is followed by the calculation of the GHG emissions attributable to an individual treatment. In Chapter 5 the emissions arising from the differing modalities and treatment regimes, including both in-centre haemodialysis (ICHD) and home haemodialysis (HHD), which are used to deliver maintenance haemodialysis are modelled, in order to inform carbon reduction strategies at the level of both individual treatments and haemodialysis programmes.

Chapter 6 presents four case studies of good environmental practice. These were identified from the literature search and survey reported in Chapters 2 and 3. The case studies were developed in collaboration with individual renal services within the United Kingdom, and illustrate how the environmental agenda may be aligned with those of care quality and financial cost. The case studies include the salvage of reject water during haemodialysis, the use of telephone consultations in place of traditional outpatient appointments in the follow up of renal transplant recipients, the retro-fitting of heat exchangers to haemodialysis machines, and the role of waste management strategies within a renal service.

Finally, Chapter 7 concludes the thesis by reviewing its key findings and discussing recommendations for future research.

The Green Nephrology Programme

The contents of this thesis draw on work undertaken by the author as part of the Green Nephrology Programme [Connor, Tomson et al., 2010]. The programme seeks to develop and implement measures to reduce the environmental impact of the provision of renal healthcare, whilst also improving the quality of this care and reducing the financial costs associated with delivering it. The Green Nephrology Programme is delivered through The Centre for Sustainable Healthcare (formerly The Campaign for Greener Healthcare), a United Kingdom charity, in partnership with many of the organisations responsible for shaping the way in which renal healthcare is provided (including NHS Kidney Care, the British Renal Society, the Renal Association, the Association of Renal Industries and the National Kidney Federation). The author was seconded from his clinical duties to work as the Green Nephrology Fellow between September 2009 and August 2010. The Green Nephrology Programme is now established as a respected programme for quality improvement in renal medicine and was featured in Sir Michael Marmot's 2010 report on health inequalities, 'Fair Society, Healthy Lives' [Marmot, 2010].

Chapter 2.

Opportunities to Reduce the Environmental Impact of the Provision of Renal Healthcare.

Introduction

The reasons why the healthcare sector, including the specialty of renal medicine, should seek to reduce its GHG emissions were discussed in the previous chapter. The infrastructure required to provide renal healthcare includes medical inpatient wards, outpatient clinics, administration services, and a relatively high use of electrical medical equipment (for example, dialysis machines). It might therefore be anticipated that measures to reduce building energy use could make an important contribution towards achieving such a reduction [O'Leary, 2010]. However, the NHS Carbon Reduction Strategy has identified nine key areas in which emissions must be reduced within the delivery of healthcare [NHS Sustainable Development Unit, 2009]. This more wide-ranging approach has been informed by the NHS Carbon Emissions Carbon Footprinting Report [Sustainable Development Commission, 2008], which suggests that building energy use contributes only 22% of the overall emissions of NHS England - an indication that, whilst initiatives to improve energy efficiency may be both visible and important, they can form only a part of the solution. Instead, a clinical transformation of the current systems and practices used to deliver healthcare is required to reduce emissions across the different areas.

Four principles have previously been proposed to support this clinical transformation: [Connor, Mortimer et al., 2010; Mortimer, 2010].

- the prevention of disease
- the education and empowerment of patients in their own care
- leaner service delivery

- the preferential use of those treatment options and medical technologies with lower environmental impacts

This chapter will consider how these principles might be applied to the provision of renal services, illustrating the approach using examples identified from the published medical literature. The chapter then focuses upon further opportunities to improve the environmental impact of three aspects of renal services that are anticipated to offer particular scope for change; the provision of dialysis, the management of waste, and the procurement of medical equipment and pharmaceuticals.

Methodology

Attempts to develop a search term that would succinctly identify those publications relating to environmental issues across all fields of healthcare proved unsuccessful, resulting in unmanageable numbers of irrelevant articles as a result of the need to include a wide variety of terms. For example, a literature search through Pubmed (http://www.ncbi.nlm.nih.gov/sites/entrez) for articles published in English since 1st January 2000 using the search term (“sustainable” OR “sustainability” OR “environment” OR “environmental impact” OR “carbon footprint” OR “greenhouse gas” OR “climate change”) returned 317,719 articles despite restricting the search to the titles and abstracts. For reasons of practicality, therefore, the literature search was limited to those articles relating to environmental issues within the field of renal medicine.

A final literature search was therefore undertaken on 8th January 2011, through Pubmed, for articles published in English since 1st January 2000. The search term, ((“dialysis” OR “renal unit” OR “renal units” OR “renal service” OR “renal services” OR “nephrology service” OR “nephrology services”) AND (“sustainable” OR “sustainability” OR “environment” OR “environmental impact” OR “carbon footprint” OR “greenhouse gas” OR “climate change” OR “waste”)), was restricted to titles and abstracts. The abstracts of the 377 articles identified were reviewed. Four publications were excluded on the basis of having arisen from work undertaken as part of this thesis (Table 1). Only a further 10 articles were of relevance, of which nine were published since January 1st 2005 (Table 2). These were retrieved and further articles of potential interest were identified from the reference lists.

Table 1: Literature search results: publications excluded on the basis of having arisen from work undertaken for this thesis.

Author(s)	Title	Reference
Connor A, Lillywhite R, Cooke MW.	The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom.	*Hemodialysis International,* 15:39-51, 2011.
Connor A, Lillywhite R, Cooke MW.	The carbon footprint of a renal service in the United Kingdom.	*Quarterly Journal of Medicine*, 103(12):965-975, 2010.
Connor A, Mortimer F.	The green nephrology survey of sustainability in renal units in England, Scotland and Wales.	*Journal of Renal Care,* 36(3):153-160, 2010.
Connor A, Milne S, Owen A, Boyle G, Mortimer F, Stevens P.	Toward greener dialysis: a case study to illustrate and encourage the salvage of reject water.	*Journal of Renal Care,* 36(2):68-72, 2010.

Table 2: Literature search results: publications considered to be of relevance to Chapter 2.

Author(s)	Title	Reference
None listed	Low carbon dialysis for James Paget.	*Health Estate*, 64(8):76-77, 2010.
James R.	Incineration: why this may be the most environmentally sound method of renal healthcare waste disposal.	*Journal of Renal Care,* 36(3):161-169, 2010.
Cheng YW, Li KC, Sung FC.	Medical waste generation in selected clinical facilities in Taiwan.	*Waste Management,* 30(8-9):1690-1695, 2010.
Agar JW.	Conserving water in and applying solar power to haemodialysis: 'green dialysis' through wiser resource utilization.	*Nephrology (Carlton),* 15(4):448-453; 2010.
Hoenich NA, Levin R, Ronco C.	Water for haemodialysis and related therapies: recent standards and emerging issues.	*Blood Purification,* 29(2):81-85, 2010.
Upadhyay A, Sosa MA, Jaber BL.	Single-use versus reusable dialyzers: the known unknowns.	*Clinical Journal of the American Society of Nephrology,* 2(5):1079-1086, 2007.
James R.	Dialysis and the environment: comparing home and unit based haemodialysis.	*Journal of Renal Care,* 33(3):119-123, 2007.
Twardowski ZJ.	Dialyzer reuse--part II: advantages and disadvantages.	*Seminars in Dialysis*, 19(3):217-226, 2006.
Hoenich NA, Levin R, Pearce C.	Clinical waste generation from renal units: implications and solutions.	*Seminars in Dialysis*, 18(5):396-400, 2005.
Park LK.	Guidelines on disposing of medical waste in the dialysis clinic.	*Nephrology News Issues*, 16(3):16-17, 2002. Note: it was not possible to obtain the full text of this article.

The use of standard literature search techniques to identify good environmental practice within healthcare is problematic. The Institute of Medicine recognises six domains of quality within healthcare, suggesting that high quality healthcare should be safe, timely, effective, efficient, equitable and patient-centred [Institute of Medicine, 2001]. Within the medical literature, it is upon these domains that the majority of the reports of treatments, technologies and patient pathways focus, although the importance of placing sustainability at heart of health service decision-making has been acknowledged [Royal College of Physicians, 2010(a)]. In many cases, therefore, the potential of a treatment, technology or patient pathway to reduce the environmental impact of the delivery of healthcare may pass unrecognised or unreported. Furthermore, where environmental benefits have been identified in articles, the terminology used to report them may be highly variable. It is therefore likely that the search has uncovered only a small proportion of the examples of good environmental practice in current practice.

This chapter is not, therefore, intended to represent a definitive report of good environmental practice occurring within renal services, but will, instead, provide an insight into the opportunities available to effect a clinical transformation of the delivery of kidney care in the United Kingdom. With this in mind, the examples described deliberately extend beyond improvements in energy efficiency to include strategies encompassing many of the different aspects of the delivery of renal healthcare.

Applying the principles of clinical transformation to renal medicine

The four principles considered to underpin a transformation to more sustainable clinical practice have previously been listed [Connor, Mortimer et al., 2010; Mortimer, 2010]. The application of these principles to the provision of renal services is now considered, and the approach is illustrated using examples identified from the published medical literature.

Disease Prevention and Health Promotion

The increasing demand for healthcare is, in part, driven by improvements in our ability to diagnose and treat disease and is contributing to the rising financial costs [Organisation for Economic Co-operation and Development, 2010] and GHG emissions [Sustainable Development Commission, 2008] associated with the provision of healthcare in the United Kingdom. Strategies designed to prevent the development or progression of diseases might be expected to reduce the rate at which the demand for healthcare rises within a population. This, in turn, might be anticipated to reduce the GHG emissions associated with the management of these diseases if, as seems likely, the emissions attributable to the preventative strategies are consistently lower than those arising from the management of the conditions in their absence. Both in individual patient care, and through broader advocacy, renal services should be encouraged to tackle the underlying causes of disease – modifying the social, economic and environmental determinants of health. The identification of effective strategies to achieve this must become a research priority.

For example, although the recent implementation of routine reporting of estimated glomerular filtration rate (eGFR) blood tests across most healthcare services in the United Kingdom was initially followed by a rise in the number of referrals to nephrology services (with a resultant increase in the workloads and, presumably, GHG emissions of these services), these referrals are now being reduced to more manageable levels whilst nephrologists are seeing fewer patients 'crash landing' with end-stage renal disease (ESRD) than was the case prior to eGFR reporting [O'Donoghue, 2009; Phillips et al, 2009; Byrne, Ford et al. 2010]. Taking admission to hospital to be a surrogate for the consumption of resources and therefore the emission of GHGs, it is to be anticipated that the unplanned commencement of dialysis will, in the longer term, generate more GHG emissions that a planned start, as the former results in more frequent and prolonged hospitalisations [Dogan et al., 2005; Lamiere & Van Biesen, 1999; Mendelssohn et al., 2011]. An improved understanding of the extent to which the reduction in patients requiring unplanned starts on dialysis lowers the environmental impact of the service as a whole will, in turn, inform the overall value of the eGFR reporting initiative to the healthcare system.

The electronic recording of patients' blood results offers further opportunities for the early detection of renal disease, thereby allowing treatment to prevent disease progression. The implementation of a computerised screening system, identifying patients with both diabetes mellitus and falling eGFR results (suggestive of progressive kidney damage) is being used to bring patients at high risk of end stage renal disease to the attention of a local renal service in a timely manner [Rayner et al., 2006]. Recent data suggest a resultant reduction in the incidence of diabetic patients requiring transplantation or dialysis, (personal communication with the author, 24th September 2010), with anticipated financial and environmental benefits.

Patient empowerment and self-care

Patient empowerment is an established component of the successful management of chronic disease, [Bodenheimer et al., 200] but its potential benefit in facilitating lower-carbon care also merits consideration. Empowered patients are both proactive and reactive in the management of their conditions, preventing and responding to the challenges their illnesses present. Such patients, for example those undertaking home-based renal replacement therapies, often require less input from healthcare professionals, potentially reducing the financial and carbon costs of the care they receive. Chapter 5 reports a comparative study of the GHG emissions attributable the provision of haemodialysis at home and in-centre.

Strategies to empower patients, and to teach them when and how to access healthcare appropriately, may play an important role in the transformation to lower carbon healthcare. Established patient empowerment tools are already in use amongst renal services. Renal Patient View is a computer system that allows patients to access the results of their blood tests and investigations, and that provides reliable information on their condition [Turner, 2006]. The service is free to, and popular with, patients [Bartlett et al., 2007].

Further opportunities are evident within other specialties. For example, the Birmingham Own Health project is a regional, evidenced-based, tele-health system that was developed to increase the level of self care for people with a range of long term conditions, including diabetes mellitus and heart disease. A strategic aim of the project is to induce a paradigm shift from predominantly face-to-face care to remote care, with the particular intention of making the service available to 'hard to reach' groups who were known not to access healthcare when provided in the traditional way. Results from both routine service monitoring and user evaluations have shown improvements in both behavioural and biochemical markers in relation to diabetes and heart disease and high levels of patient satisfaction [National Archives, 2008(b)]. Diabetic nephropathy was the most common primary renal disease in patients commencing renal replacement therapy* (RRT) in the United Kingdom in 2008 [Byrne, Ford at al., 2010]. Although difficult to quantify, it is likely, therefore, that the GHG emissions attributable to the running of a service such as the Birmingham Own Health project (which is delivered remotely using telephones) will be heavily outweighed by reductions in the emissions resulting from the reduced use of traditional models of healthcare, including dialysis, due to improvements in patient health.

Leaner service delivery

Developed within the car manufacturing industry, 'lean' is a tool to improve flow and eliminate lower value activities (and waste). Duplication is common within healthcare systems. The application of lean methodologies and the reduction of waste in particular, might therefore be anticipated to reduce the associated GHG emissions and financial costs. Indeed, lean methodology has formed the backbone of diverse initiatives to meet many challenges within the healthcare setting. Examples include improving patient safety [Varkey et al., 2007], enhancing the timeliness and quality of the reporting of radiological [Cavagna et al., 2003] and histological [Serrano et al., 2010] investigations, and reducing patient waiting times in Emergency Departments [Ng et al., 2010], elective [Kullar et al., 2009] and semi-elective services [Ahmed-Jushruf & Griffiths, 2007].

Lean methodologies might be used to drive reductions in the GHG emissions of renal services through the elimination of 'low value' healthcare treatments, technologies and models of care. Although challenging to define, these might include: those treatments that have been proven to be ineffective or, worse still, to do more harm than good; those for which there is no supporting evidence and which are not being delivered in such a way that this evidence can be developed; those for which evidence of efficacy does exist, but which are being provided outside of the

* The term 'renal replacement therapy' refers to the two forms of dialysis (haemodialysis and peritoneal dialysis), and also to renal transplantation.

context in which such evidence was gathered; and those that use resources which would produce a better balance of benefit to harm if invested in a different service for the same patients [Gray, 2007]. Healthcare research has an important role to play in ensuring that only safe and effective healthcare is provided; the carbon footprint of the clinical trials required to determine reliable information is significant [Lyle et al., 2009; Burnett et al., 2007], but is likely to be far less than that of the ineffective treatments, technologies and models of care that may persist in the absence of such trials. Indeed, the leading funding body of healthcare research within the NHS has recently developed guidelines to reduce the GHG emissions arising from the research trials it supports [Lyle et al., 2009; National Institute for Health Research, 2010].

Examples of 'low value' practices exist within renal medicine. The provision of haemodialysis is both financially expensive and resource intensive. Yet our understanding of when to initiate (and discontinue) this treatment, in the settings of both acute and chronic kidney diseases, remains far from complete [Cruz et al., 2010; Macedo & Mehta, 2010; Wright et al., 2010]. It is likely, therefore, that many patients are receiving unnecessary dialysis treatments, perhaps for prolonged periods of time, and possibly to the detriment of their health [Wright et al., 2010; Clark et al., 2011; Cooper et al., 2010]. An improved understanding of issues such as these may result in valuable financial and carbon savings, as well as a better patient experience.

The principle of removing waste can be extended beyond the treatments themselves to include the manner of their delivery. Chapter 4 describes how patient travel contributes to the overall GHG emissions of a renal service. Initiatives to reduce patient travel, through services such as the outreach clinics that are increasingly common in Australia [National Health and Hospitals Reform Commission], might not only improve the patients' experience but also reduce the associated emissions. Similarly, patients often attend multiple clinics for different, but related, health concerns without co-ordination of appointment dates. For example patients with diabetic nephrology may be seen in both the diabetes and nephrology clinics. Opportunities exist to reduce patient travel emissions, and once again improve the patients' experience and care, by running joint clinics for these patients.

Alternatively, perhaps patients may not even need to attend the clinic in person to receive their care. Indeed, many clinicians, faced with the challenge of providing increasingly high standards of care to growing numbers of patients with rising expectations, are exploring models of remote care. These offer patients and clinicians a number of benefits including enhanced access to healthcare, heightened continuity of care, patient empowerment and time savings. Clear benefits to the patients and the environment also arise from the reduction in patient travel. Remote care is not appropriate when formal physical examination is a likely necessity, but is well suited to the provision of follow up for chronic disease, which forms much of the workload of a renal service. Yet, whilst remote care has become an established method of reducing the burden on primary care and Emergency Departments, relatively little information exists on its use within renal medicine. Videoconferencing can facilitate routine consultations between nephrologists and dialysing patients [Whitten & Buis, 2008]. Studies have also demonstrated that telemedicine can improve access to healthcare, reduce costs, and lessen patient travel, in both haemodialysis and peritoneal dialysis [Jennett et al., 2003].

Remote healthcare spans a number of the principles of clinical transformation. Not only does the elimination of patient and staff travel represent the removal of waste from the system, but such strategies can contribute to patient empowerment and the promotion of self care; this is illustrated in Chapter 6 through the report of the use of telephone consultations to provide routine follow up to renal transplant recipients. However, further research should focus on the safety of remote care and upon measuring its benefits (including those of an environmental nature), in order that the fourth principle of clinical transformation – that more sustainable pathways of care are preferred wherever possible – may be realised by ensuring that local funding models support remote healthcare services within renal medicine.

The preferential use of lower carbon technologies, treatments and patient pathways

Clinicians and, where appropriate, patients should be encouraged to choose clinically effective treatments with the optimal environmental profiles. However, this will require that measures of environmental impact are included in the evaluation of medical technologies, treatments and pathways of care. The results of the literature search outlined earlier in this chapter illustrate that such measures are rarely, if ever, assessed, although such an undertaking is now advocated by the National Institute of Healthcare Research [National Institute of Healthcare Research, 2010].

Assuming that the spectrum of future research is broadened to support this strategy, it should not be expected of clinicians that they make such decisions on an individual patient basis. Instead, these considerations must be incorporated into not only the policies and guidance defining the nature of high quality kidney care (such as the National Service Framework for renal services in the United Kingdom) but also the systems designed to drive this care (such as the payment and commissioning systems).

Technological advances present opportunities for lower carbon models of care. The introduction of an e-consultation service, facilitating the timely provision of advice by nephrologists to clinicians in primary care, has been shown to reduce the number of referrals of patients with mild to moderate chronic kidney disease [Stoves et al., 2010]. The confidence of primary care clinicians to manage these patients locally was improved and the specialist recommendations were well followed.

This chapter has considered firstly, the need for a clinical transformation and, secondly, the principles with which such a transformation might be effected within renal medicine, illustrating each principle with examples of good environmental practice identified from the medical literature. It is important to note that the sustainability agenda has not been responsible for any of the developments in the provision of renal medicine provided as examples of improved sustainable practice. Indeed, in almost all cases, the primary driver for change has been an improvement in one or more of the six domains of quality in the healthcare as described by the Institute of Medicine [Institute of Medicine, 2001]. It is clear, therefore, that the transformation to more sustainable renal medicine can be achieved alongside improvements in patient care.

Consideration will now be given to further opportunities to improve the environmental impact of three aspects of renal services that offer particular scope for change; the provision of dialysis, waste management, and the procurement of medical equipment and pharmaceuticals.

Opportunities to lessen the impact of dialysis upon the environment

The provision of RRT to patients with ESRD forms a major component of the workload of most renal services in the United Kingdom. Whilst transplantation represents the optimal form of RRT for the majority of patients, the scarcity of donor organs means that the prevalence of patients receiving dialysis (411 per million population) is greater than that of patients with a functioning renal transplant (363 per million population) [Byrne, Steenkamp et al., 2010]. Although, as these figures indicate, the absolute number of patients receiving maintenance dialysis in the United Kingdom remains small, a number of factors combine to suggest that the provision of dialysis is likely to make a major contribution to the GHG emissions of a renal service: the therapy is required life-long; the treatments are required frequently; and each treatment consumes substantial resources (energy and water) and produces considerable plastic and packaging waste. Furthermore, in the United Kingdom, 43% of all patients receiving RRT undertake ICHD [Byrne, Steenkamp et al., 2010], for which the thrice-weekly return travel to the dialysis facility is most commonly undertaken by car [The Health and Social Care Information Centre, 2010], a particularly carbon intensive form of transport [DEFRA, 2009].

HHD is arguably more cost-effective [Baboolal et al., 2008] and offers an improved quality of life [Finkelstein, 2007]. Whilst robust evidence of improved patient outcomes by way of randomised controlled trials is lacking (primarily as a result of the difficulties presented by the inherent selection bias), many clinicians are increasingly convinced of the superiority of HHD and very few would argue it to be genuinely inferior. However, the uptake of HHD varies dramatically between and within countries, and has declined considerably in many regions [MacGregor et al., 2006]. Significant expansion of HHD is likely to be possible in many countries, in part through embracing evolving technologies.

The importance of understanding the environmental impacts of both ICHD and HHD is therefore clear. There has been one study on this subject to date [James, 2007], in which methodological difficulties in analysing the absolute carbon footprints of these two modalities prompted the adoption of a comparative approach in which quantification of the differences in their environmental impacts was attempted. Chapter 5 reports the first analysis of the absolute carbon footprints of these treatment modalities, including both direct and indirect emissions. Chapter 6 presents case studies of individual measures to reduce the water use, energy consumption and waste production associated with haemodialysis. Meanwhile, further opportunities to reduce the environmental impact of the provision of haemodialysis also exist, of which a few are discussed here.

Water Consumption during Haemodialysis

Water is a finite natural resource. The proportion of the world's population living in water stressed areas is projected to rise from one third to almost half by 2030 [Food and Agriculture Organization of the United Nations, 2007; Organisation for Economic Co-operation and Development, 2008]. The quantity of water consumed is a particularly striking feature of the use of a standard haemodialysis machine. A patient receiving a four hour haemodialysis treatment, with a standard target dialysate flow rate of 500 millilitres per minute, will require 120 litres of dialysate. In most facilities, this is drawn from the mains water supply and the purification process commonly employs reverse osmosis to remove residual salts. Reverse osmosis systems reject around two thirds of the water presented to them. Accounting for the water necessary to prime and cleanse the dialysis machine, a total volume approaching 500 litres of mains water is required per patient per treatment.

The 'reject water' from the reverse osmosis system is high-grade water that commonly meets the biochemical criteria for potable water and, although it remains legally unacceptable for drinking its use for alternative purposes poses no infection risk as reject water does not come into contact with either the patient or the dialyser [Agar et al., 2009]. However, in the overwhelming majority of haemodialysis services worldwide, large volumes of reject water are simply lost to drain. A case study in Chapter 6 presents the simple methodology required to recycle reject water for other uses (such as laundry, sanitation and low pressure boiler feed), illustrating the financial savings that have been realised by a United Kingdom renal service. The extent to which reject water is salvaged within the renal services of England, Scotland and Wales is explored in Chapter 3. In Chapters 4 and 5, consideration is given to the contributions made by water use to the carbon footprints of a renal service and different haemodialysis regimes (including those of the new technologies with far smaller water consumptions) respectively.

Energy use in Haemodialysis

Although water is a precious resource, Chapter 4 will demonstrate that its use within renal services is unlikely to contribute substantially to their overall carbon footprint (as opposed to their ecological footprint). Accordingly, therefore, the salvage of reject water results in relatively small reductions in GHG emissions. In this regard, the use of solar or other alternative energy sources to power dialysis and water purification machinery appears more promising and is now being piloted by one renal service in Australia [Agar et al., 2010]. Reductions in actual energy used may be achievable through the use of heat exchangers (described in Chapter 6) and variable pump speed reverse osmosis plants [Health Estate Journal, 2010].

Dialysate Delivery, Production and Use

The use of central delivery systems to provide concentrated dialysate acid reduces both dialysate wastage and the plastic waste derived from dialysate containers (which may prove difficult to recycle as the possibility of residual acid often discourages local recycling facilities). Further environmental savings are possible if this concentrate is delivered in 1:44 concentration (the maximum that most machines can proportion), thereby reducing the emissions related to the transportation of large volumes of liquids that are predominantly produced in mainland Europe. This benefit would be greater still if the dialysate components were to be delivered in powder form and reconstituted on site, however availability and concerns around composition errors and contamination presently discourage many units from this option.

Clinicians should also be made aware of the considerable increases in reject water production (around 72 litres per treatment) that arise from increasing the dialysate flow rate from 500 to 800 millilitres per minute, and the lack of firm evidence that this strategy actually increases delivered dialysis dose at all [Golper & Ward, 2009]. Furthermore, increasing the dialysate flow rate requires a greater volume of dialysate concentrate. In the absence of central delivery systems, this frequently results in the opening of a second container of dialysate (with any remainder being discarded), thereby doubling both the financial cost and the amount of plastic waste attributable to the dialysate usage.

Dialyser Reuse

GHG emissions arise from the manufacture and distribution of dialysers. In the United States, although many dialysis facilities dispose of dialysers after a single use, 40% of facilities re-use them (usually for between 10 and 20 dialysis treatments). It has been estimated that, in the United States, dialyser usage contributes over 4,000 tonnes of polymer waste annually, and that this figure would fall to approximately 1,000 tonnes if all dialysis facilities were to re-use dialysers for ten dialysis treatments [Upadhyay et al., 2007]. Dialyser reuse reduces not only those emissions attributable to their manufacture and distribution, but also those arising from the incineration of this polymer waste. Dialyser reuse also reduces the amount of dialyser-related packaging waste.

Dialyser reuse has been primarily driven by financial considerations [Twardowski, 2006] and is most commonplace in the United States. A further advantage, the prevention of first-use syndromes through the improvement in blood-membrane biocompatibility, has become less significant as more biocompatible membranes have become available. The health concerns around infection risk and exposure to residual germicide from the decontamination process are sufficiently small that dialyser reuse is undertaken in 40% of dialysis facilities in the United, although rates are falling.

Yet the sustainability of dialyser reuse is unclear. The use of germicides, such as formaldehyde and peracetic acid, in the decontamination process raises environmental concerns as it produces increased liquid waste (heated water, chemicals and disinfectants) and chemical vapours (such as hypochloric acid). The disinfection process also increases the use of disposable waste (such as masks, gloves, aprons and test strips). As both single-use practice and more frequent dialysis regimes are becoming increasingly common worldwide, there is a pressing need for further advances in dialysis waste management. Chapter 5 reports the first quantification of the GHG emissions saved through dialyser reuse.

The Management of Clinical Waste in Renal Medicine

Haemodialysis is dependent upon the use of sterile, single-use items such as dialysers and blood lines, as well as non-sterile items such as dialysate, and therefore produces considerable amounts of waste. Previous studies suggest that a single haemodialysis session produces approximately 2.5 kilograms (kg) of solid clinical waste, of which 38% is plastic [Hoenich et al., 2005]. Estimates of the amount of solid clinical waste produced annually by a patient undertaking thrice weekly haemodialysis vary between 241 and 390 kg per year [Hoenich et al., 2005; James, 2010]. The discrepancies may be attributable, in part, to the use of dialysers and blood lines of differing weights [James, 2010], and neither estimate accounts for the substantial cardboard and polythene waste that is often associated with packaging. Whilst these figures compare favourably with the estimated 617 kg of clinical waste produced per year by a patient undertaking a standard continuous ambulatory peritoneal dialysis regime (an alternative treatment to haemodialysis) [Hoenich et al., 2005], the proportion of patients undertaking the latter therapy nationally is far smaller than those receiving haemodialysis [Byrne, Steenkamp et al., 2010] and the haemodialysis programmes of United Kingdom renal services must therefore be expected to aggregate substantially more waste than the peritoneal dialysis programmes.

The vast majority of healthcare waste undergoes disposal through incineration or landfill, with only small proportion being sent for recycling or reuse. Much of the waste generated from dialysis products and their packaging falls into the category of clinical waste (that which is infectious or hazardous). Clinical waste is subject to the Environmental Protection Act of 1990 in the United Kingdom and is almost invariably incinerated, although newer technologies for the disposal of particular types of clinical waste are emerging.

Uncertainty exists regarding the respective environmental profiles of incineration and landfill for healthcare waste. Although the incineration of healthcare waste, using modern incinerators, has recently been argued to confer a number of environmental advantages over disposal to landfill (not only does incineration allow for the possibility of energy recovery, but it has also been suggested that the overall GHG burden associated with landfill may also be greater than previously believed) [James, 2010], disposal to landfill remains the cheaper option and is therefore presently widely favoured for the non-clinical waste produced by dialysis. Further research is required to better understand the possible environmental dividends from preferentially diverting waste to incineration.

Although there is little published literature on this topic, renal services should be strongly encouraged to develop sustainable waste management strategies. The segregation of waste at source is vital to ensure that non-clinical waste (e.g packaging) is, where possible, recycled. For example, although commonly incinerated or sent to landfill, plastic dialysate concentrate containers should not enter the clinical waste stream unless contaminated by blood or bodily fluids, but should instead be recycled or simply reused [James, 2010]. However, waste segregation is often poorly achieved in the hospital setting, where clinical waste bags have been reported to contain between and 10.2% and 53.2% non-clinical waste by weight [Tudor et al., 2008]. The case study described in Chapter 6 provides an insight into how improvements might be made within a dialysis unit. Although the effective segregation of waste requires staff education and the availability of extra physical space, the benefits appear worth the investment - in the case of haemodialysis it has been estimated to yield up to a 29% reduction in the waste produced per treatment [James, 2010].

The Interface with the Renal and Pharmaceutical Industries

Procurement contributes 60% of the total NHS emissions, with pharmaceuticals and medical equipment being primarily responsible [Sustainable Development Commission, 2009]. This figure unmasks the indirect emissions related to the manufacturing process. The interface between the suppliers of consumable medical goods and those delivering healthcare therefore represents an important opportunity for improving sustainability within renal services. The process of procurement is a case in point. The incorporation of sustainability criteria by renal services into all procurement contracts for dialysis consumables might be expected to incentivise improvements amongst industry competitors. However, the extent to which sustainability criteria are applied by renal services, and the nature of any criteria in use, is presently unclear, and will be explored in greater detail in Chapter 3. Developments in the use of sustainability criteria within renal services are also discussed in the concluding chapter.

Dialogue between the industry and healthcare providers is also vital at each stage of the product life cycle; for example, are all the components of a product routinely utilised? Will suppliers remove packaging for recycling at delivery? Can recyclable plastics be used to make the packaging?

Sustainable procurement, on a global scale, might also be employed to drive down those GHG emissions arising in the supply chains of pharmaceuticals, but the process will be a slow one. Influencing the consumption of medications may appear more immediately feasible. Up to forty percent of medications prescribed to those with chronic conditions are never taken [World Health Organisation, 2003]. This figure may be even higher amongst the renal population, in whom polypharmacy and complicated medication regimes are commonplace. These medications are rarely returned to the pharmacy and, in any case, the Royal Pharmaceutical Society of Great Britain dictates that all returned medications must be destroyed (as the quality can no longer be guaranteed), entailing considerable financial and environmental costs.

Attention must therefore focus on reducing drug wastage, in which clinicians can play a major role through three simple measures. Firstly, they should identify and modify poor compliance. Secondly, prescribers should strive to reduce 'inequivalence', whereby different items on the same prescription are allotted differing durations. This requires patients to manage their repeat prescriptions. Some patients will struggle to order only the items they require and instead will choose to re-order all the items regardless of their existing stock, leading to drug hoarding. Finally, the prescription of excessive quantities should be avoided, as this leads to greater wastage when changes are made. This is particularly important when medications are first commenced and changes are most likely. Reducing the need for medications through the adoption of healthier, lower carbon, lifestyles will also help to reduce the need for medications and, in turn, their associated emissions.

The Impact of Environmental Pollution

This chapter has focused primarily upon the environmental gains that may be achievable through service redesign within renal medicine. However, the converse – that renal services and patients might benefit from reductions in environmental pollution made outside of the healthcare setting – might also be true. Solvents, such as hydrofluorocarbons, are man-made chemicals with high global warming potentials that are used to manufacture products such as paints, adhesives, automotive electronics, computers and medical equipment. Occupational solvent exposure hastens the progression of existing chronic kidney disease and may also contribute to its initiation [Jacob et al., 2007]. Similarly, heavy metals such as cadmium, mercury and lead, are non-biodegradable, have long half-lives, and represent a major environmental hazard. They are also nephrotoxic at very low doses, through both acute and chronic exposures, and cause varying degrees of nephropathy from tubular dysfunction to ESRD [Barregard et al., 2010]. These examples illustrate how public health strategies to limit environmental pollution, for example through reductions in the use of these metals in dental amalgams (mercury) or smoking cessation strategies (cadmium), might reduce the burden of kidney disease.

Even within renal services, direct exposure to man-made chemicals in clinical products may be harming both patients and the environment. Dialysis products made from polyvinylchloride typically contain the softener di-(2-ethylhexyl)-phthalate, which is toxic to reproduction according to the European Union Directive 67/548/EEC on Classification and Labelling of Dangerous Substances. The 2008 European Union Risk Assessment on di-(2-ethylhexyl)-phthalate highlighted the need to limit risks to consumers from medical equipment used in long term haemodialysis [European Chemicals Bureau, 2008]. Plastic dialysis products that are free of polyvinyl chloride and di-(2-ethylhexyl)-phthalate are now available and the wholesale elimination of di-(2-ethylhexyl)-phthalate could be achieved through alterations to renal services' procurement policies.

Are Measures to Reduce the Environmental Impact of Renal Services Affordable?

The cost of limiting emissions to below 550 parts per million CO_2eq has been estimated at 1% of the global per capita consumption per year, whilst allowing unchecked emissions may cost the world up to 20% of global consumption per year, albeit not realised for up to 200 years [Stern, 2007]. Thus the argument that measures to reduce emissions will cripple the world's economy, and that further economic growth should precede their introduction, is weak, and such measures should be implemented now. But, given that the current economic climate will ensure that healthcare systems, including the NHS, will face unprecedented reductions in resources (or, at the very least, diminished expansion in the face of ongoing increases in demand), should they too invest in green technologies now?

It might be argued that they should, as the aforementioned economic arguments apply less well to the NHS, in which increased activity is dependent upon economic growth, rather than being a driver for it. Indeed, the spiralling costs of the healthcare system in the United States are considered to be a major threat to the nation's economy. Instead, with lean principles and the removal of waste at the heart of many of the green initiatives appropriate to renal services, the potential for a profitable return on an investment is real, as is illustrated through the case studies detailed in the Chapter 6.

Conclusion

It has been suggested in this chapter that improvements in energy efficiency alone will be insufficient to allow renal services to meet the challenging targets of the NHS Carbon Reduction Strategy [NHS Sustainable Development Unit, 2009]. Instead, it is proposed that a clinical transformation of the way in which renal services are delivered is required, and that service redesign should be focused on those aspects adding real value to patient care. The principles that might underpin such a transformation have been illustrated with examples of good environmental practice identified predominantly from the medical literature. However, it is clear that many opportunities to improve the sustainability of renal services will not previously have been reported. Chapter 3 therefore examines the current practices of renal services throughout England, Scotland and Wales, seeking primarily to identify further examples of good practice and assess the extent to which improvements in sustainability might be made.

Chapter 3.

A Survey of Sustainability in Renal Services in England, Scotland and Wales.

Introduction

Chapter 2 considered how the principles of a clinical transformation to lower carbon healthcare might be applied within the specialty of renal medicine. The chapter discussed examples of good environmental practice that are either already occurring within the provision of renal healthcare or that might be translated across from current practice within other specialties. Whilst these examples were predominantly identified from the medical literature, it was acknowledged that standard literature search techniques might be expected to identify only a proportion of the examples of good environmental practice that have been reported and that, furthermore, many examples will not have been reported in the literature. For these reasons, a survey of the renal services of England, Scotland and Wales was undertaken, in order to better understand both the current and best practices of resource use. This chapter reports the findings of The Green Nephrology Survey of Sustainability in Renal Units in England, Scotland and Wales [Connor & Mortimer, 2010]. The survey was undertaken as part of the Green Nephrology Programme, within which context the objectives of the survey were: to establish a baseline for the sustainable use of resources within renal services; to identify examples of good environmental practice; to ascertain opportunities for reducing the environmental impact of renal services; and to act as an engagement and educational tool for the respondents of the survey and the units that they represented.

The meanings of the term 'sustainability' are wide-ranging. Within this thesis it is used to describe a reconciliation of the environmental, social and economic demands affecting resource use in order to facilitate 'sustainable development' (the pattern of resource use that allows us to meet our current needs, whilst preserving the environment in order that the needs of future generations might also be met) [United Nations General Assembly, 1987].

Methodology

The survey focussed upon the environmental threat posed by climate change and was designed to address opportunities for the reduction of GHG emissions (mitigation strategies) and the preparedness for climate change (adaptation strategies). Short sections on governance and attitudes to sustainability within renal services were also included. The questions were informed by the way in which renal services are provided in the United Kingdom, and by the NHS Carbon Emissions: Carbon Footprinting Report, which revealed that, across the NHS in England, 22% emissions arise from energy use on site, 16% are attributable to travel, and 62% result from consumption of procured goods and services [Sustainable Development Commission, 2008]. The questionnaire comprised 41 stems, each with a varying number of closed-response questions. A free-text box was also provided with the majority of these stems and respondents were invited to add information they considered to be of relevance. The full questionnaire is available online at www.greenerhealthcare.org/webfm_send/76 (last accessed 28th February, 2011).

Seventy eight adult and paediatric renal units were identified across England, Scotland and Wales from the Renal Registry website (www.renalreg.com). Sixty-three of these units provided a contact to complete the survey, of which 58 (92.0%) submitted responses between October 27th 2009 and March 9th 2010. Respondents were predominantly Green Nephrology Local Representatives (individual staff members with widely differing roles within their local units, who were actively identified as part of the Green Nephrology Programme between September 2009 and January 2010). Each contact was offered the opportunity to complete the survey online or in hard copy, and up to three ‘reminder’ emails were sent to maximise the response rate.

Feedback was provided to participating units by way of individualised annotated slide sets. These slide sets included the aggregated national results and, to facilitate comparison, the data submitted by the individual unit. Green Nephrology Local Representatives were encouraged to present these slide sets at local departmental meetings in order to provoke discussion and bring about change. Although a potentially effective tool to stimulate change in healthcare service delivery, the use of league tables (at either a regional or national level) to display the results was not considered appropriate as it had not been suggested to respondents as a possibility prior to their participation on behalf of their units. Alternatives to providing simply the aggregated national results as the comparator for each unit's performance were considered: it was rarely considered necessary to state the gold standard (for example, it is clear that the gold standard for the use of low energy light bulbs is for them to be present in 100% of fittings); the extent of variation existing around the national averages may have been of interest, but it was considered important to keep the results, and their interpretation, simple.

Results and Interpretation

As not every respondent submitted data for every question, percentages are also quoted in this report to allow a more accurate appreciation of the results. Almost all responses (55, 95%) related to hub units, whilst just three (5%) detailed a satellite unit.

Building Energy Use

Building energy use (heating and cooling, hot water and electricity consumption) contributes 22% of the overall NHS carbon footprint [Sustainable Development Commission, 2008] and offers a number of 'quick wins' for renal units seeking to reduce their carbon footprint.

Lighting

The level of lighting was reported to be appropriate in most (42, 75%) units, with only five (9%) considering their units to be too bright. Although low-energy light bulbs are used in 'all or almost all' lights in over a quarter (17, 30%) of surveyed units, they are used 'in none or very few' of the lights in 23 (40%) surveyed units, suggesting an opportunity for improvement. When not required, lights are 'usually or always' switched off in over half (35, 61%) of surveyed units and are 'occasionally' switched off in a further 16 (28%) surveyed units. The results suggest that this could be improved through the more widespread use of motion sensors, which are not used at all in the majority (36, 63%) of surveyed units.

Heating

Inaccessible thermostat and heating controls render it impossible for staff to control the heating in 35 (61%) of the surveyed units. Furthermore, air chilling facilities are not automatically switched off when the heating is switched on in 29 (51%) surveyed units. Shading is provided for south facing windows in only 36 (63%) surveyed units. Overall, it was felt by staff that appropriate temperatures were maintained in only 35 (63%) units. Renal units could therefore be encouraged to ensure that their staff can control room temperatures, whilst appreciating the needs of the patients when doing so (as, for example, patients undergoing dialysis often feel cold).

Energy Use within Information Technology

Although the benefits of switching off information technology equipment overnight (financial and environmental savings, improved computer updating and running speeds) are being recognised, with 34 (60%) surveyed units actively encouraging their staff to switch computers off, only six (11%) units have automatic mechanisms in place to ensure that this occurs. This is a 'quick win' that could be more widely adopted.

Equipment

The recapture of heat from hospital equipment represents an opportunity to reduce electricity use. Only 14 (25%) of surveyed units reported recapturing heat from dialysis effluent. Although this value is almost certainly an under-representation of the true number (the presence of heat exchangers, which are increasingly incorporated into modern haemodialysis machines as standard, may not be immediately apparent to respondents unfamiliar with the machines utilised in their unit), it does suggest that the simple process of retro-fitting heat exchangers to dialysis machines without them might allow some of the remaining units to recapture heat and reduce electricity use. This is explored as a case study in Chapter 6. Improving on the seven (13%) Central Sterile Services Departments reporting to recapture heat from the process of sterilizing medical equipment may be less feasible however. Meanwhile, only 13 (23%) surveyed units reported having policies to preferentially purchase energy efficient equipment, and these policies are often inconsistent (for example, in one unit the energy rating of fridges is considered important, whilst that of dialysis machines is not).

Energy Sources

The use of lower-carbon, renewable energy sources reduces fossil fuel consumption and could undoubtedly be undertaken more widely by renal units, and their parent hospitals, both through local energy generation and through the procurement of energy from a provider with a genuine commitment to renewable energy sources. Two surveyed units (4%) currently generate energy from solar panels, with plans are in place to fit panels in two further units, although no units currently generate energy from wind turbines.

Patient and Staff Travel

Travel contributed 16% to the overall NHS carbon emissions [Sustainable Development Commission, 2008], but might be expected to contribute more significantly to the footprint of renal services given that the predominant form of RRT, ICHD [Byrne, Steenkamp et al., 2010], necessitates thrice weekly return journeys to hospital. Geographical factors will influence the potential for individual units to reduce the carbon footprint of associated travel. The majority of respondents felt that their units covered an equal mix of urban and rural areas (32, 55%), with 20 (35%) covering predominantly urban areas.

Staff Travel

The trusts of 46 (81%) units have signed up to the Cycle to Work scheme (www.cyclescheme.co.uk) whilst 47 (83%) units provide secure cycle parking and 39 (68%) have adequate shower and changing facilities. Walking and cycling were considered to be unsafe in 12 (21%) units, suggesting that it may be difficult to improve on these figures.

Changes to staff shift patterns might enable greater use of public transport. Although 54 (95%) respondents considered their units to be reasonably or highly accessible by public transport, staff shift patterns do not correspond to the public transport timetables in 28 (49%) of cases, with a further 10 (18%) units unclear about this. It was noted that those staff on early or late shifts are often poorly served by public transport. Car share schemes operate in 29 (51%) of units (or trusts), although respondents commented that trusts rarely offer incentives for their uptake.

Patient Travel

As over half of surveyed units (37, 65%) do not actively provide information about public transport or encourage its use, public transport is probably also underused by patients as well as staff. Although anecdotally a source of much frustration to dialysis patients, 39 (68%) units reported that treatment schedules are designed to correspond to patient travel timetables and thereby allow efficient journey planning. Only 11 (19%) surveyed units predominantly use low emission vehicles for patient travel and it was noted that renal units may have no direct control over such services.

Given the potential health co-benefits [Woodcock et al., 2009], renal units should ensure that active transport (cycling and walking) is a genuine option for those patients and staff wishing to pursue it. For example, some units reported offering more flexible patient transport planning, providing transport home for those patients who preferred to walk to their dialysis sessions (as the treatment may leave patients feeling tired). Twenty-four (42%) of surveyed units currently provide information on the health benefits of active transport to patients. Telemedicine offers the opportunity to reduce unnecessary travel [Yellowlees et al., 2010]. The provision of remote healthcare, in different guises, was reported in seven (12%) surveyed units.

Procured Goods & Services (Consumption and Procurement Practice)

Procurement is responsible for 62% of the GHG emissions attributable to NHS England, with pharmaceuticals and medical equipment contributing 30% of total emissions [Sustainable Development Commission, 2008]. With many patients with renal disease experiencing polypharmacy, and the widespread availability of renal replacement therapies being highly dependent upon the use of consumable items of medical equipment, the reduction of this aspect of the carbon footprint of renal services must be an important longer term goal.

Sustainable Procurement Strategies

The widespread incorporation of sustainability criteria into the procurement contracts put out to tender by renal services represents an opportunity to reduce the environmental impact of the renal industry. These criteria might initially be used to encourage the measurement of different aspects of the environmental impact of the supplying organisations and their products, with future iterations focusing upon improvements in these measures.

The benefits of sustainable procurement extend beyond its benefit to the environment. An NHS organisation is many things, including: an employer; a purchaser of goods and services; a manager of transport, energy, waste and water; a landowner; a commissioner of building work; and an educator. How such an organisation behaves may therefore impact at a local level upon the health and well being of the people and society, the economy and the environment. As significant components of the healthcare organisations of which they are part, renal services can therefore make an important contribution towards sustainable development within their day to day running. The Good Corporate Citizenship model, within which procurement forms one of the six strands of development, allows renal services (and their parent organisations) to showcase this contribution and to set an example [Sustainable Development Commission, 2006].

Renal services may also make considerable financial savings through sustainable procurement, reducing utility bills and operating costs through the purchase of energy, water and resource efficient products, services and buildings. The significant waste management costs incurred by NHS organisations might be reduced by the purchase of environmentally preferable products [Tudor et al., 2008]. Furthermore, the implementation of sustainable procurement strategies might help renal services to meet the challenges of the impending regulatory and fiscal policies for carbon reduction, such as the NHS Carbon Reduction Strategy [NHS Sustainable Development Unit, 2009] and the Carbon Reduction Commitment Energy Efficiency Scheme [Department of Energy and Climate Change, 2010].

However, despite the benefits to renal services, the survey results indicate that sustainability criteria are currently incorporated into only 7% of contracts for peritoneal dialysis supplies, 9% of contracts for haemodialysis supplies and 4% of contracts for office supplies. Respondents also highlighted the exclusion of sustainability criteria from the recent Scotland-wide consumable procurement contract, despite calls for their inclusion from clinicians. Potential barriers to sustainable procurement must therefore be considered, and informal feedback from respondents indicates that implementation is hindered by a number of factors, including: difficulties determining effective sustainability criteria; competing considerations within the procurement process, including financial cost; a lack of guidance at the level of individual renal services; and the different patterns of procurement currently existing amongst, and within, different renal services.

The determination of effective sustainability criteria represents a particular challenge. The criteria must assess genuinely measurable standards of sustainability, and should lie within the reach of the majority of supplying organisations, yet also result in improvements in current practice. They should relate, ideally, to both the product and the organisation, including the relevant supply chains. They should be afforded appropriate weighting within the contract and, finally, they should not contravene European Union directives regarding fair trade.

Printers and Paper Use

Further 'quick wins' are possible by addressing printer and paper use. Printers in renal units are rarely (12, 21%) set to draft quality and almost never set to print double-sided (7, 12%). Less than a third of units purchase recycled paper (17, 30%) despite twice as many recognising the importance of recycling by providing recycling bins in their administrative areas (38, 67%). Email is preferred to paper copy for letters to primary care in only 4 (7%) units.

Clinical Supplies

Haemodialysis fluids are delivered to units in individual cartridges (rather than by central delivery) in 24 (44%) surveyed units, increasing plastic and packaging waste. Similarly, 24 (44%) surveyed units reported not purchasing their dialysates in the highest available concentration, increasing the volumes that must be transported. Furthermore, no effort is made to recycle the extensive plastic and paper packaging associated with single-use dialysis equipment in 38 (69%) units whilst, of those that do, the majority (57%) estimate that they recycle less than 40% of it.

Healthcare Waste Management

Healthcare produces two main forms of waste; non-clinical (domestic) waste and clinical waste. Whilst the former may be sent to landfill or, preferably, recycled, the latter must be incinerated. As was discussed in Chapter 2, further research is required to better understand the respective environmental impacts of the different disposal strategies for healthcare waste. Meanwhile, however, renal services should still be encouraged to develop sustainable waste management strategies, to which the effective segregation of waste at source is vital. Only that waste which genuinely requires incineration should enter the clinical waste stream, and recyclable domestic waste should not be sent to landfill. Waste segregation requires staff education and facilities, which occupy extra space, to stream clinical and non-clinical waste.

Although 34 (60%) respondents felt that efforts to stream waste were moderately satisfactory in their units (with 'domestic waste sometimes ending up in clinical waste bags and sharps bins'), this subjective response is at odds with that of more objective studies [Hutchins, 2009]. Regular waste auditing within renal services may challenge staff beliefs around, and improve upon, the current standards of waste segregation.

Recycling bins for non-clinical packaging and plastic wastes are not present in the clinical areas of 41 (73%) and 45 (79%) surveyed units respectively, indicating potential for 'quick wins'. Similarly, many suppliers are able to collect and directly re-use the pallets and cardboard boxes used in the delivery of dialysis supplies, but this is presently only occurring in 27% (for haemodialysis related delivery waste) and 15% (for peritoneal dialysis related delivery waste) of surveyed units. Only 40% of those units from whom pallets and cardboard are not collected by the supplier are sending these items for recycling themselves.

Food Packaging and Recycling

The extent to which the packaging associated with inpatient food is recycled is also poor. Recycling rates below 25% were reported by most units for plastic (30, 58% of units), aluminium (31, 60%), paper (20, 40%) and glass (25, 48%) forms of catering waste. However, as some units reported recycling greater than 80% of each of these items, improvements in this area should be feasible. Respondents commented that the outsourcing of catering to national organisations reduces the opportunity to influence recycling and the sourcing of local produce.

Water Conservation

Water is a precious and finite natural resource - but one that is under threat [Intergovernmental Panel on Climate Change, 2007]. The same water stores that were available to the 300 million inhabitants of the earth in Roman times are now shared amongst a global population of 6.7 billion people, more than one third of whom now live in water-stressed countries [Food and Agriculture Organization of the United Nations]. We therefore have a responsibility to use water carefully. As was discussed in Chapter 2, the needless 'loss-to-drain' of reject water during the production of the dialysate for haemodialysis remains by far the most profligate use of water within healthcare. Presently only two surveyed units (4%) have installed the simple methodology required to conserve this high grade water. This not only allows it to be put to alternative purposes (such as laundry, sanitation systems and low pressure boiler feed) but has also been shown to make sound financial business sense [Agar et al., 2009; Connor, Milne et al., 2010]. A detailed report of the conservation of reject water from haemodialysis is included as a Case Study in Chapter 6.

Water-saving taps are not present in any sinks in the majority (36, 64%) of surveyed units, and are present in only a few sinks in nine (16%) of the remaining surveyed units, indicating that their widespread adoption should be encouraged. Despite renal units often having large roof areas, only one (2%) unit reported harvesting rain water.

The Built Environment

Buildings should be designed to encourage sustainable development and support lower carbon activity in every aspect of their fabric and function [NHS Sustainable Development Unit, 2009]. However, more than half of respondents (32, 56%) felt that the impact of staff and patient travel had borne little influence on where new facilities were built, whilst almost one third (18, 32%) believed that opportunities to incorporate natural light, heating and ventilation were passed over. Most surveyed units offer both patients (39, 70%) and staff (40, 73%) little access to green spaces. The majority of respondents (36, 64%) were unable to ascertain whether either new buildings or refurbishments were required to meet specific Building Research Establishment Environmental Assessment Method (BREEAM) ratings. More positively, reported examples of good practice included the use of ground heat source pumps and heat recapture from activity within buildings, whilst one unit is investigating the possibility of a wood chip boiler.

How important is climate change perceived to be by renal units?

Given that respondents to the survey were predominantly Green Nephrology Local Representatives, it is perhaps not surprising that 33 (65%) believed that reducing the carbon footprint of the provision of renal services is 'very important and must be prioritised' (with the remaining 35% of respondents to this question believing that it is 'important but that other improvements to the service should take priority'). However, many respondents also commented that there was considerable ambivalence to the topic within their units, and the results indicate that renal services do not presently perceive climate change to be of direct relevance to their practice. Most surveyed units (52, 91%) have not undertaken a sustainability audit (which would typically include assessments of energy, transport and waste management). The majority of surveyed units (50, 88%) do not have Green Action Plans and do not include sustainability as a regular topic in the departmental management meetings (49, 86%). Although 16 (29%) surveyed units have a published policy on carbon reduction and/or sustainability, this is likely to be undertaken at Trust level.

No information on environmental issues is included in staff induction programmes at 49 (86%) surveyed units. No training in the relevance of environmental issues to their daily work is provided in 48 (84%) of surveyed units. Most surveyed units (47, 83%) have no system in place to allow staff to contribute suggestions for carbon reduction within the unit, a source of frustration for many respondents.

Preparedness for the Effects of Climate Change

Heat waves, flooding, storms and other extreme weather events are likely to increase in frequency as a result of climate change [Costello et al., 2009]. The Climate Change Act 2008 requires that all statutory sectors, including the health sector, have robust adaptation plans in place [National Archives, 2008(a)]. It is therefore heartening to find that most surveyed units have emergency strategies to cover interruptions to the power (56, 98%) and water (48, 84%) supplies. However, most surveyed units (30, 54%) do not have provisional arrangements should weather disrupt the travel plans for the haemodialysis patients, whose lives would be endangered were they to be unable to attend their thrice-weekly in-centre treatments.

Only seven (12%) surveyed units have incorporated the National Heat Wave Plan into their policies [Department of Health, 2010(a)]. Increases in the rate of emergency admissions to hospital during heat waves have been reported for patients with kidney disease in both the United Kingdom and elsewhere [Kovats et al., 2004; Hansen et al., 2008], suggesting that such patients may be at greater risk than most from extreme temperatures. This may be particularly true for those patients with chronic kidney disease who are not yet requiring dialysis, and in whom, it might be postulated, a smaller degree of intravascular hypovolaemia (resulting from the increased insensible losses that occur during periods of hot weather) may have a more detrimental impact upon kidney function. Furthermore, it has been suggested that medications, including some of those commonly prescribed to patients with kidney disease, may increase susceptibility to dehydration during heat waves [Hajat et al., 2010]. However, only 18 (32%) surveyed units provide formal information to patients regarding how to care for themselves during heat waves, whilst only half (31, 54%) of surveyed units are able to keep temperatures in their clinical areas below 26 °C during heat waves.

Limitations

The design of this survey suffered from the conflict between the need to gather sufficiently quantitative data in order that the future iterations of the survey might permit the monitoring of sustainability, and the desire to ensure that respondents (newly appointed to their roles and without data collection systems in place for this information) could complete the survey without undue difficulty. As such, not all of the desired data were requested and surrogate metrics were employed in many instances instead. It might be hoped that future iterations of the survey may collect more quantitative data. For example, the interest in lightbulbs results primarily from the carbon emissions related to the energy that they use. The optimal metric to represent this might perhaps therefore be the lightbulb-associated CO_2eq produced per metre of indoor space over a given time period. However, requesting such information from each unit is clearly not practical, and this iteration of the survey simply asked respondents to estimate (within specified percentage groupings) the extent to which low-energy bulbs are used in their unit. This example also illustrates the role that sub-metering within hospitals (in this case, sub-metering of the lighbulb-associated energy use with a renal unit) could play in identifying and reducing energy usage and financial costs.

The respondents to this survey were predominantly Green Nephrology Local Representatives. These individuals had committed to working with the Green Nephrology Programme to achieve its wider goals on behalf of their units. It might be anticipated, therefore, that these individuals would have a keener interest than most in the issues around climate change, and that this might in turn enable them to provide more accurate and insightful answers to the survey questionnaire. However, it should be noted that these individuals have widely differing roles within their local units, and this diversity might also have influenced their responses.

Respondents were not found for 15 of the 78 originally identified renal units. It is possible that those units that did not respond were those practising least sustainably (particularly as respondents were predominantly Green Nephrology Local Representatives), introducing a degree of bias within the results. However, there were no apparent demographical differences between those units providing responses and those not doing so, and, overall, the results were considered to adequately reflect practice across the United Kingdom.

Discussion

The primary objective of this survey was to establish a baseline for environmental practice within the delivery of renal services across England, Scotland and Wales. In essence, the Green Nephrology Programme is a series of individual Clinical Systems Improvement projects interwoven amongst the widespread development of a sustainability culture within kidney care. Future iterations of this survey will allow the magnitude and direction of any change resulting from these interventions to be monitored. The role of the Renal Registry reflects an appreciation of the importance of monitoring outcomes within renal medicine. However, the discipline of patient safety – another relatively recent and rapidly evolving dimension of clinical care from which the Green Nephrology Programme can learn – has been cited as an area in which the inappropriately late adoption of such monitoring has hindered further progress in the field [Vincent et al., 2008].

The survey was also intended to support a transformation to lower carbon care by identifying the most fruitful areas for attention. It was designed to identify examples of good environmental practice already being achieved in individual renal units, with a view to facilitating their widespread adoption through the development of case studies such as those reported in Chapter 6. The survey was also designed to identify those aspects of the provision of renal care in which current practice is commonly particularly damaging to the environment, but in which simple interventions might lead to significant improvements. The Green Nephrology Programme was aligned with the objectives of the national 10:10 Campaign and these ‘quick wins’ were presented in poster format as the 10:10 Renal Checklist [The Centre for Sustainable Healthcare, 2010].

Finally, the use of slide sets to convey the results of the survey to the participating units has ensured that the work has an educational component, raising awareness of the Green Nephrology Programme, providing receptive members of the renal community with ideas to improve the environmental profiles of their units, and highlighting the extent and importance of the change required.

Implications for Renal Units

The results of this survey indicate the extent to which the sustainability of resource use within renal services might be improved. In response to these results, the Green Nephrology Programme is encouraging renal services to develop a sustainability culture within their units, with every unit in England, Scotland and Wales appointing a Green Nephrology Local Representative and sustainability becoming a regular feature at their departmental meetings. Units are encouraged to implement a system to allow staff members to contribute improvement ideas. The development of strong relationships between renal services and their respective Estates and Procurement departments will enable the introduction of more wide-reaching sustainability initiatives. Where possible, patients should be offered the opportunity of involvement in their unit's green initiatives.

The results of this survey support the premise that sustainable healthcare requires not only sustainable estates management but also sustainable clinical practice. Sustainability should become a key consideration in the development of care pathways and existing practices should be reviewed. For example, can patient travel be safely reduced by telephone consultations or through the administration of iron infusions in the community?

Implications for the Green Nephrology Programme

The results of this survey have informed the choices of case studies developed to date (the conservation of reject water, the retro-fitting of heat-exchangers to dialysis machines, the provision of follow up to transplant recipients by telephone consultation and recycling within renal units are all reported in Chapter 6). The results also highlight areas in which further work should be focused, including patient and staff travel, information technology, and implementing sustainable procurement strategies.

Variation exists between the demographics of the populations served by different renal units, the services that are provided, and the pathways and infrastructure used to deliver these services. Although our survey facilitates crude comparisons of the environmental impact of individual aspects of the services provided by different renal units, it was not possible to attribute an accurate weighting to impacts of these parameters, and a comparative analysis of the overall sustainability of the different renal units was not possible. At a more simplistic level, however, no individual units, or models of service, were readily discernible as more sustainable. In particular, there were no obvious differences in the sustainability of those units providing acute transplantation services or paediatric care.

Areas for Further Research

Although vital for the longer term success of the Green Nephrology Programme, no attempt was made to measure the existence of a 'sustainability culture' within the renal community with this survey. Similarly, no attempt was made to ascertain any measures taken by individual units to encourage more sustainable lifestyles amongst their patients. Finally, as has been mentioned previously, this survey was unable to accurately assess the overall sustainability of an individual renal service. A better understanding of both the overall impact of a renal service upon the environment, and the contribution of the different aspects of this service to its overall impact, is therefore required. This is explored in detail in Chapter 4.

Chapter 4.

The Carbon Footprint of a Renal Service in the United Kingdom.

Introduction

Although many opportunities to reduce the environmental impact of renal healthcare (and, in particular, the GHG associated with its delivery) have been described in the preceding chapters, it is clear that a clinical transformation of the provision of renal services will be required if the challenging targets set out by the NHS Carbon Reduction Strategy are to be met [NHS Sustainable Development Unit, 2009]. Meanwhile, the recent NHS Next Stage review [Department of Health, 2008] has outlined a similar need for service change and innovation within the NHS in order to improve the more widely recognised domains of quality within patient care. Such service reconfigurations present an opportunity to integrate the principles of a clinical transformation towards lower carbon care into renal services.

However, there has been little evaluation of this opportunity to date, with the current economic climate focusing consideration upon the financial, rather than environmental, impacts that any reconfigurations might have. Indeed, the evidence base to support the implementation of individual strategies to provide lower carbon renal healthcare is currently slender. The literature review described in Chapter 2 retrieved only a handful of publications relating to sustainability within renal medicine, and the examples of good environmental practice identified through the survey reported in Chapter 3 were occurring predominantly in isolation and without evidence of shared learning. Similarly, a recent systematic review concluded that there has been very little original research into the implementation or evaluation of actions to reduce the contribution made by the NHS to climate change [Nichols et al., 2009]. Further research, including carbon footprinting studies, is therefore required to better understand the environmental impacts of healthcare technologies, treatments and pathways, such that these impacts can be considered during service reconfigurations.

Chapters 4 and 5 begin to address this deficit in our understanding by reporting carbon footprinting studies of standard renal services and treatments respectively. Chapter 4 begins by considering what is meant by a carbon footprinting study and the different approaches that may be taken, before exploring, by way of a literature review, the extent to which such techniques have been applied within the healthcare sector as a whole (appreciating that very little work of this nature has previously been undertaken within the specialty of renal medicine itself). From this platform, the remainder of the chapter reports a study of the carbon footprint of a single renal service, the Dorset Renal Service, and estimates the GHG emissions arising from the provision of renal healthcare across England. These results might act as an evidence base for future decision making in the transformation to lower carbon kidney care, highlighting the areas of the service with the greatest carbon footprint and facilitating the evaluation of alternative service configurations. The methodology also presents a template for renal services wishing to assess their own carbon footprint.

What is a Carbon Footprint?

Although there is only one scientific journal devoted to life cycle assessment [Finkbeiner, 2008], many such assessments have been undertaken in the last decade. The methodology has evolved, and its use has become more widespread, as concern regarding the threats posed by global climate change has risen. Within this context, the term 'carbon footprint' has been used ubiquitously in both public debate and the scientific literature. Broadly speaking, it has been used to refer to an assessment of the gaseous emissions resulting from a product or process, with particular attention given to those emissions considered to be of relevance to climate change. However, the need to settle upon a concise and unambiguous definition appears to have been recognised only relatively recently.

The Carbon Trust (2007) considers carbon footprinting to be “a technique for identifying and measuring the individual GHG emissions from each activity within a supply chain process step and the framework for attributing these to each output product (we [The Carbon Trust] will refer to this as the product’s ‘carbon footprint’).” However, many possible configurations to the measurement and quantification of a carbon footprint exist within this terminology. Important aspects that must therefore be described in the methodology of a carbon footprint analysis should include, but are by no means limited to, the following:

- **the scope of the emissions**. For example, the calculation of a carbon footprint might include every GHG specified by the Intergovernmental Panel on Climate Change (IPCC) 2007 report [Intergovernmental Panel on Climate Change, 2007]. Alternatively, it might only include the six GHGs described in the Kyoto Protocol Reference Manual [United Nations Framework Convention on Climate Change, 2008], or even simply CO_2 itself. Limited data availability makes it more difficult to quantify particular GHGs and, although it may be possible to present a partially aggregated indicator, it may be considered more appropriate to include only CO_2 in order that the study is more interpretable (and therefore comparable).

- **the source of the emissions.** A decision may be made not to include those emissions that do not stem from fossil fuels, for example, such as CO_2 emissions from soils.

- **the impact of the life cycles of the goods and services lying within the boundaries of the footprint.** Consideration must be given to whether the analysis is concerned only with the direct emissions attributable to the use of these goods and services, or whether it will also include the indirect emissions embodied in their production processes. Ultimately, the clear definition and description of boundary issues is arguably of greater importance than decision of what to include and exclude, as it is this that facilitates comparison and replication.

- **the inclusion of carbon offsetting, and what this actually encompasses.** It might be argued, for example, that the use of renewable energy is a form of offsetting.

- **the units of measurement.**

Some of these questions are addressed in an attempt by Wiedmann and Minx to refine the definition further, with their proposal that "the carbon footprint is a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" [Wiedmann & Minx, 2008].

At its most basic, the process of developing a carbon footprint therefore involves the setting of boundaries, the identification of the GHGs to be included, the choice of the most appropriate methodology, the definition of the accounting rules and timeframe, the collection and assessment of the data, and the consideration of the degree of uncertainty within the assessment.

The requirements set out by the earlier definitions can be met through differing methodologies, influenced in part by the aims of the study and the availability of the data. An environmental input-output analysis offers a top-down approach to developing a carbon footprint, in which input-output tables of economic accounting data are used to determine economic activity within a sector, which is then combined with data regarding the emissions attributable to the sectors. The boundary is therefore defined by the economic system, allowing the inclusion of direct and indirect emissions. This was the methodology used in the NHS England Carbon Footprinting study [Sustainable Development Commission, 2008].

However, the nature of this approach is such that it lacks detail as it assumes homogeneity of financial prices, outputs and their carbon emissions at sector level. Hence it is less appropriate for use in the assessment of smaller organisations, processes or individual products. An alternative approach is the process analysis or life cycle assessment (LCA), in which specific primary and secondary process data are generally collected from the bottom up. This is well suited to the assessment of the environmental impact of individual products or services from the cradle to the grave, but, as a system boundary must be set, this approach can lead to truncation errors of unknown size. In order to harness the strengths of these two techniques, they may be integrated into a hybrid environmental input-output life cycle assessment (EIO-LCA) method. This preserves the detail and accuracy of the bottom up approach for the more important processes, whilst the coverage of the majority of the less significant processes by the input-output assessment avoids truncation error and fills gaps where primary data are lacking, for example within the supply chain. A further benefit of this hybrid approach is the enhanced understanding of the uncertainty inherent in the result. This is further discussed under the heading 'Uncertainty in the Results'.

Standardisation of carbon footprinting methodology is ongoing. PAS2050 is a Publically Available Specification (PAS) for assessing product or service life cycle GHG emissions, and was developed under the auspices of the Carbon Trust, the Department for Environment, Food and Rural Affairs (DEFRA), and the British Standards Institution [British Standards, DEFRA & Carbon Trust, 2008]. It is of relevance to the approach taken in this study that the PAS 2050 methodology is based upon a LCA method, with input-output analysis playing a negligible role. However, given the aforementioned benefits of the hybrid approach, it is anticipated that alternative standardisations currently under development will afford a greater prominence to input-output analysis.

What a Carbon Footprint is not

This thesis focuses primarily upon the contribution made to climate change by the provision of renal healthcare, and the calculation of a carbon footprint quantifies the GHG emissions released by the service or product being assessed. GHG emissions contribute to anthropogenic climate change, but represent only one component of the environmental impact of the service or product. A carbon footprint does not assess other potential social, economic or environmental impacts such as non-GHG emissions, acidification, eutrophication, toxicity or biodiversity.

The Application of Carbon Footprinting within the Healthcare Sector

There have been very few published carbon footprinting studies relating to the healthcare sector. A literature search was undertaken on 2nd November 2010, through Pubmed, for articles published in English. The search term ("greenhouse gas" OR "greenhouse gases" OR "carbon footprint" OR “life-cycle assessment”) was restricted to titles and abstracts. The titles and, where considered necessary, abstracts of the 1656 articles identified were reviewed. A total of only 8 articles were subjectively considered to report carbon footprinting studies relating to the healthcare sector.

After the exclusion of an article arising from work undertaken for this thesis [Connor, Lillywhite et al, 2010], only two of the carbon footprinting studies retrieved in this search attempted to include both the direct and indirect emissions attributable to the organisation or process under consideration [Chung & Meltzer, 2009; Somner et al., 2008], although the magnitude of the contribution of supply chain emissions to the carbon footprints of healthcare in both England and the United States is now appreciated [Sustainable Development Commission, 2008; Chung & Meltzer, 2009]. The challenge of including these emissions is illustrated by the rather simplistic use, in a study comparing the carbon footprints of medical and surgical treatments for gastro-oesophageal reflux [Gatenby, 2011], of a measure of the overall carbon intensity of the healthcare delivered by the NHS. In the absence of available specific emissions factors, the author of this study applied a figure for the overall carbon intensity of healthcare that had been derived from a previous study [Sustainable Development Commission, 2008] to all aspects of the treatments being studied except the procurement of medical equipment and pharmaceuticals.

Three of the retrieved studies included travel emissions alone, [Zander et al., 2010; Davie et al., 2010; Wootton et al., 2010] as did two further articles identified from the references of retrieved publications [Callister & Griffiths, 2007; Crane, 2006]. Meanwhile, a proof-of-concept study, centred around the collection of energy consumption data from two anonymous North American emergency medical services, has shown that it is feasible for individual healthcare specialty services to provide data regarding both building energy use and travel [Blanchard & Brown, 2009]. The emissions attributable to the water used during the process of surgical scrubbing, and the energy require to heat it, have also been reported [Somner et al., 2008].

In keeping with the findings of Chapter 2, this literature search again highlighted the problem of identifying the relevant literature within the field of sustainability within healthcare. For example, despite the choice of terms, the search did not retrieve an article reporting an LCA of reusable and disposable plastic anaesthetic trays [McGain et al., 2010], for which the key-words were "anaesthesia", "drug trays", "disposable", "reusable", "single-use" and "costs", although the article in question is cited by the Pubmed database. Similarly, the search did not retrieve a report of the carbon footprints of HHD and ICHD, which is discussed in Chapter 5 [James, 2007].

The study of most relevance to this chapter was not, in fact, cited on Pubmed. The carbon footprint of NHS England was calculated using an input-output table comprising 178 industrial sectors, with expenditure data derived from national level supply-and-use tables [Sustainable Development Commission, 2008]. Industrial sector emissions factors were derived from emissions data provided by National Statistics Environmental Accounts. As travel emissions were estimated from National Travel Survey data and added to the resultant footprint, this was a top-down approach complemented by bottom-up data where available. A similar environmental input-output lifecycle assessment using expenditure data was performed to estimate the carbon footprint of the United States Health Care Sector [Chung & Meltzer, 2009].

As was mentioned in Chapter 2, the GHG emissions released by clinical research trials have been investigated by way of an assessment of the aggregated carbon footprint of a sample of twelve randomised controlled clinical trials [Lyle et al., 2009]. Data were collected for a number of activities, including the travel of staff and participants, and the energy used to manufacture the information technology equipment required to run the trials. Standard emissions factors were applied to these data. The factors used for pharmaceuticals and medical equipment were taken from the NHS England study [Sustainable Development Commission, 2008]. The total CO_2

emissions were calculated to be 941 tonnes and were predominantly due to travel. Once again, although cited on Pubmed, this article was not retrieved by the literature search described above.

An early step towards meeting the challenging targets set out by the NHS Carbon Reduction Strategy must be the establishment of a sound understanding of the sources, and magnitudes, of the GHG emissions associated with the delivery of healthcare. The results of this literature search, and others [Nichols et al., 2009], suggest that the evidence base to support carbon reduction strategies specific to renal medicine (and, indeed, all specialties) is presently insufficient. It is upon this premise that the assessments of the GHG emissions attributable to both an individual renal service and the provision of renal healthcare across England are now reported. The assessment of the carbon footprint of the Dorset Renal Service includes both direct and indirect emissions and is, therefore, the first fully comprehensive report of the carbon footprint of an individual healthcare specialty service.

The Carbon Footprints of a Single Renal Service in the United Kingdom and the Delivery of Renal Healthcare across England.

Aims

The primary aim of this study was to calculate the carbon footprint of the Dorset Renal Service. The secondary aims were to estimate the carbon footprint of the provision of renal healthcare across England and to provide a methodology to allow other renal services to ascertain their own carbon footprints more readily.

Methodology

The Dorset Renal Service Model

In order to understand this report, it is essential to appreciate that the Dorset Renal Service consists of a number of component parts provided across a number of geographical sites. The Dorset Renal Service is based within a District General Hospital (Dorset County Hospital Dorchester, DCH) and provides renal services at three further sites (Yeovil District Hospital, YDH; Poole General Hospital, PGH; Royal Bournemouth Hospital, RBH). It serves a geographical area of approximately 1300 square miles (see figure 1) and a population of 865,000 people. It does not provide paediatric nephrology services.

Figure 1. The geographical area covered by the Dorset Renal Service.

The components of the Dorset Renal Service are inpatient care, outpatient care, peritoneal dialysis, haemodialysis, transplantation and administration. Inpatient care is provided in a 14 bed ward (DCH). Outpatient care is provided through the 7 clinics held each week across the 4 sites (DCH, RBH, PGH, YDH). A single pre-dialysis nurse runs 2 clinics a month across two sites (DCH, RBH) and undertakes occasional home visits. Haemodialysis is provided to a total of 225 patients, who dialyse across the 4 centres (55 at DCH, 60 at RBH, 63 at PGH, 45 at YDH). A further 2 patients undertake HHD. Two dialysis technicians provide services to DCH, RBH and YDH. Peritoneal dialysis is provided from 2 centres to 54 patients (15 from DCH, 39 from RBH). Patients receiving renal transplants have their investigative work-up undertaken at the hospital local to the clinic they attend. There is one Transplantation Specialist Nurse who undertakes twice monthly clinics and makes occasional home visits. Transplantation surgery is performed at a tertiary centre (Southmead Hospital (SMH), Bristol), 65 miles away by road. After discharge, patients are typically followed up as outpatients at the tertiary centre for an average of three weeks, prior to referral back to their local clinic.

A medical team of five consultants and three registrars provide care across the components of the service. Three junior doctors provide care to inpatients at DCH. A nurse-led renal anaemia team provide care across the different components of the service. Iron infusions are undertaken at DCH. Three dieticians provide care across the different components of the service. Social work care is provided by two social workers working solely within the Dorset Renal Service. Occupational therapy is provided by one occupational therapist, who can refer to local services where necessary. A psychologist provides care to patients across the different components of the service. Within the Dorset Renal Service, physiotherapy is only provided to inpatients. Aside from transplantation, surgery integral to the care provided by the Dorset Renal Service (dialysis access surgery, parathyroidectomy) is primarily undertaken at DCH. Patients requiring inpatient stays are managed on the renal ward. A small amount of day-case dialysis access surgery is undertaken at RBH. Administrative work is undertaken primarily at DCH. Domestic staff provide cleaning services at each of the different components of the service.

Emissions Terminology

The Kyoto Protocol recognises six GHGs in its targets [United Nations Framework Convention on Climate Change, 2008]. CO_2 is released from both natural events (such as volcanism) and the burning of fossil fuels by man. As a result of the latter, CO_2 is, by some margin, the most prevalent anthropogenic GHG within the atmosphere aside from water vapour. Emissions of GHGs may be quantified in terms of their global warming potential - the global warming potential of 1 kg of the gas in question being equivalent to the amount of a reference gas that would produce an effect of similar magnitude over a defined time period. The IPCC recognises three time periods, of which the most commonly used is 100 years. CO_2 is the gas most commonly used as the reference gas. Therefore the emissions of other gases are frequently expressed in the units of CO_2eq. Within the US Health Care Sector, approximately 80% of the total global warming potential has been attributed to CO_2 emissions [Chung & Meltzer, 2009]. Similarly, over 85% of the NHS England GHG emissions were CO_2 emissions [Sustainable Development Commission, 2008]. Furthermore, this remained uniform between sectors and subsectors, with minor exceptions being food procurement and waste, which have increased GHG emissions due to production and degradation of organic material. This figure of 85% is also comparable to the CO_2 proportion from all United Kingdom emissions. However, the remaining five GHGs recognised by the Kyoto Protocol have higher global warming potential than CO_2 and therefore contribute significantly to climate change, even if emitted in small volumes. This study includes the two of these GHGs (CH_4 and N_2O) anticipated to be of the greatest relevance to healthcare-associated emissions. The contribution made by refrigerants was considered to be negligible and was therefore excluded.

Unit of Measurement

Total emissions, including CO_2 and non-CO_2 (CH_4 and N_2O) GHGs, have been calculated across the components of the Dorset Renal Service and are reported in tonnes of CO_2eq per year.

Overview of Methodology

As was outlined earlier, the methodology employed in the analysis of a carbon footprint may be influenced in part by the availability and nature of the data. This was a component analysis study, in which the contributing parts of the Dorset Renal Service were identified and data relating to their emissions were collected.

A 'bottom up' approach was adopted to collate the data relating to building energy use, travel, waste and water use. The data collected were disaggregated in source and physical in nature. As such, this part of the study might be considered to be a process analysis, or LCA, in which emissions were determined at each stage of the production process. Established emissions factors were applied to reconcile the data to a common unit of measurement (CO_2eq).

However, the complexities and innumerable processes involved in healthcare provision render the process analysis approach to environmental accounting impractical for the analysis of all aspects of the Dorset Renal Service. The procurement data were therefore collected predominantly through a 'top down' approach (for example, pharmaceutical and medical equipment data), complemented by data collected using a 'bottom up' approach where possible (for example, construction). The procurement data were therefore less well disaggregated across the different components of the Dorset Renal Service (haemodialysis, peritoneal dialysis, inpatient care, outpatient care, transplantation and administration) at their respective sites (DCH, RBH, PGH, YDH, SMH). For example, the pharmaceutical data for the RBH peritoneal dialysis service were inextricably embedded within the pharmaceutical data for the RBH haemodialysis service. The procurement data were also predominantly collected as economic data, as physical data were not consistently available. Once again, established emissions factors were applied to reconcile the data to the common denominator (CO_2eq). Whilst the approach to the procurement sector therefore shares similarities with that in an environmental input-output analysis, in that the boundary defined by the provision of care by the Dorset Renal Service is mimicked by its economic system, the mix of economic and physical data did not lend itself to an environmental input-output analysis in the true sense of the term.

Overall, this hybrid of approaches has allowed the inclusion of both indirect emissions (such as those arising from the manufacture of pharmaceuticals) and direct emissions (such as those arising from the burning of fossil fuels to facilitate travel). This report adheres to the principles and definitions defined within PAS2050 [British Standards, DEFRA & Carbon Trust, 2008]. Any exceptions to this are clearly described and their rationale explained.

Consumption versus Production Emissions

In keeping with the NHS England carbon footprint study [Sustainable Development Commission, 2008], the emissions for the Dorset Renal Service have been calculated on a consumption basis, and are the sum of emissions from three sources: direct carbon emissions from building energy use; direct carbon emissions from patient, visitor and staff travel; and procurement emissions. Procurement emissions can be defined as the embodied emissions associated with production, consumption and disposal of all goods and services consumed within the Dorset Renal Service or arising in the industrial supply and disposal chains. These goods may originate overseas, and the consumption of the Dorset Renal Service (and the delivery of renal healthcare across England) therefore has a global reach.

The emissions from the three sources outlined above were calculated for each of the components (inpatient care, outpatient care, haemodialysis, peritoneal dialysis, transplantation, and administration) of the Dorset Renal Service at each of the sites at which they are provided (DCH, RBH, PGH, YDH, SMH), and summated to calculate the carbon footprint of the Dorset Renal Service.

Calculating the Carbon Footprint of the Provision of Renal Services throughout England

Although data relating to procurement and building energy use are submitted to national databases by Acute Trusts incorporating renal services, it is not possible to isolate the contribution of the renal services to this data and it is not therefore possible to directly calculate the carbon footprint of the provision of renal services across England through this approach.

Instead, an estimation of the carbon cost of the provision of renal healthcare across England has been reached through extrapolation of the results of the carbon footprint of the Dorset Renal Service. The methodology of such an extrapolation should ideally account for the considerable variation existing between individual renal services. One such source of variation is the extent to which resources are allocated to the different components of the service (haemodialysis, peritoneal dialysis, inpatient care, outpatient care, transplantation and administration), and the numbers and proportions of patients accessing these components. Unfortunately, within the sectors, the aggregated nature of much of the data (particularly within the procurement and travel sectors) prevents accurate allocation of the carbon footprint of the Dorset Renal Service to its component parts, and an approach in which comparisons of the sizes of the components of the different services was incorporated is therefore not feasible.

Instead, the approach has been as follows. Data from the Renal Registry includes calculations of the observed and expected sizes of the prevalent RRT populations (those patients receiving haemodialysis, peritoneal dialysis or with a functioning transplant) for geographical areas [Byrne, Steenkamp et al., 2010]. The observed and expected sizes of the prevalent RRT populations are combined to produce a standardised prevalence ratio for each geographical area. The standardised prevalence ratio for the Dorset population is 0.79, whilst that of the Bournemouth and Poole population is 0.84. The standardised prevalence ratio for the area covered by the Dorset Renal Service has therefore been considered to be 0.81 (splitting the difference between the two areas, but weighting the resulting value towards that of the Dorset population as the Dorset Primary Care Trust contributes 57.5% of the total population covered). It has then been assumed that the 'size' of the Dorset Renal Service is approximately 81% of that of a 'typical' renal service, and also that a linear relationship exists between the size of a renal service and its carbon footprint. The carbon burden of the delivery of renal healthcare across England has therefore been reached by the application of an uplift factor (100/81, or 1.234567) to the carbon footprint of the Dorset Renal Service, and multiplying this by the number of renal services serving the population of England.

It should be recognised that the need for RRT depends on many factors, including social and demographic factors such as age, gender, social deprivation and ethnicity. The comparison of crude prevalence rates by geographical area can therefore be misleading, and the results of this approach can therefore be considered to be only an estimate of the carbon footprint of the delivery of renal healthcare across England.

Data Sources

Two types of data are necessary to calculate a carbon footprint: activity data and emissions factors. The former relates to the amounts of materials and energy involved in the service or product being analysed, whilst the latter allow conversion of these quantities into GHG emissions. In keeping with the requirements of PAS2050 [British Standards, DEFRA & Carbon Trust, 2008], the activity data are almost exclusively primary data (determined by direct measurements made within the service). The two exceptions to this are the data sourced for waste (in which activity data were estimated from a combination of primary and secondary data –

namely peer-reviewed publications) and building energy use (in which secondary data relating to the hospitals rather than the renal departments were collected).

This section also outlines the context of any assumptions that have been made during the collection of the data, and the emissions factors that have been applied. These assumptions and emissions factors are documented in greater detail in dedicated sections within this description of the methodology.

Building Energy Use data

Emissions relating to the building energy use by the different components of the Dorset Renal Service are calculated from data submitted by the respective Estates Departments to the Estates Return Information Collection (ERIC) database. This database provides the electricity, gas, oil, coal hot water and steam use of the hospitals in which the components of the Dorset Renal Service are situated. The data are provided in gigajoules. For the purposes of this study, the data are converted to kilowatt hours (kWh) and multiplied by DEFRA emissions factors (in kg CO_2eq per kWh).

The proportion of floor space occupied by the Dorset Renal Service within each of the NHS facilities was used to calculate the building energy use attributable to it from the data submitted by the respective facilities to the ERIC data.

Where floor space is shared between the Dorset Renal Service and other services (for example, the outpatients clinics), the building energy use attributable to the Dorset Renal Service has been determined on the basis of the proportion of the time for which the area is used by the Dorset Renal Service. For example, the Outpatients Department in DCH is used by the Dorset Renal Service for two of the ten sessions per week, and 20% of the building energy use relating to the Outpatients Department has therefore been assigned to the Dorset Renal Service.

The building energy use of the DCH Radiology Department that is attributable to the Dorset Renal Service has been estimated from data relating to the proportion of its workload that is requested by the Dorset Renal Service, and an estimation of the proportion of the floor space required for a single patient episode.

Two components of the Dorset Renal Service (the haemodialysis units in YDH and PGH) do not contribute building energy use data to the ERIC data. The building energy use data for these components were sourced directly from meter readings.

Travel data

'Travel' is defined as the movement of people, and 'transport' as the movement of goods and services. In this analysis, transport emissions from goods and services are contained within their sub-sector procurement emissions. Where it was necessary to determine distances for staff, patient and visitor travel from postcodes, these were calculated using GoogleMaps (http://maps.google.co.uk).

Emissions relating to staff business and commuting travel are calculated from data derived from staff travel surveys undertaken within each component, and at each site, of the Dorset Renal Service. These surveys collected information for each member of staff regarding the distances travelled over given periods of time and the modalities of travel used (car, bus, train, active transport, air travel). These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per kilometre (km), were applied to these data.

Emissions data relating to visitor travel were calculated from estimations of travel data derived from the National Transport Survey 2006 [Department for Transport, National Statistics, 2006]**.** DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to outpatient clinics are calculated from data derived from patient travel surveys undertaken within each clinic held at each site. These surveys collected information from each patient regarding the distance travelled and the modality of travel used (car, bus, train, active transport). These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to outpatient clinics with the both the pre-dialysis nurse specialist and the transplant nurse specialist are calculated from data derived from the postcodes of patients attending these clinics over a three month period and the sites at which they attended. Assumptions were made about the modality of transport used. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to dialysis treatments are calculated from data derived from the patients' postcodes and the postcodes of the sites at which they received dialysis. Data regarding the most common modality of travel for each patient were included. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to the inpatient ward (to receive inpatient treatment as an inpatient or as a day case) were calculated from a two month sample of patients. Distances travelled where obtained from postcodes. Assumptions were made about the modality of this travel. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to the peritoneal dialysis departments were calculated from data derived from patients' postcodes and the postcodes of the sites at which they received treatment. Assumptions were made to provide data regarding the most common modality of travel and the number of visits. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to attend follow-up appointments at SMH during the weeks following transplantation surgery were determined from the postcodes of patients undergoing transplantation during the accounting period. The number of journeys was estimated on the basis of the time between their surgery and the point in time at which they were referred back to the care of the Dorset Renal Service. Assumptions were made about the modality of travel used. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to attend for pathological investigations were estimated from assumptions regarding the number of patients undergoing blood tests, their modality of travel, and the return distances that they would travel to attend for these blood tests. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to attend for iron infusions were calculated from a six month sample of patients. Distances travelled were obtained from postcodes. Assumptions were made about the modality of this travel. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Emissions relating to patient travel to attend for radiological investigations were calculated from a year's sample of patients. Distances travelled where obtained from postcodes. The modalities of travel used were estimated, based on the average one way distance and data regarding modality and journey length taken from the National Transport Survey, 2006. These data were extrapolated up to represent annual data. DEFRA emissions factors, in kg CO_2eq per km, were applied to these data.

Procurement data

The footprinting technique used in this report calculates carbon emissions relating to procurement from expenditure data (from the Procurement Department, DCH) and industrial sector emissions factors (from National Statistics of Environmental Accounts data and from DEFRA). Whilst the expenditure data have been collected for the defined accounting period, they have been deflated to 2004 values as the emissions factors for supply chain emissions that have been used in this study were produced from economic input-output tables of 2004 prices. A deflation factor of 1.121363 was applied. This was derived from data regarding the annual rates of inflation between 2004 and 2009 (obtained from the website of the Office for National Statistics [Office for National Statistics, 2011]). The exceptions to this approach were the collection of water and waste activity data, for which physical data (rather than economic data) were collected.

Emissions data relating to pharmaceuticals are calculated from data on the financial expenditure by the Dorset Renal Service on pharmaceuticals (from the Pharmacy Department, DCH) and DEFRA emissions factors.

Emissions data relating to medical equipment are calculated from data on the financial expenditure by the Dorset Renal Service on medical equipment (provided by Procurement Department, DCH, as expenditure through NHS Supply Chain and as non-stock purchases). Medical equipment predominantly includes, but is by no means limited to, the items of disposable equipment required by medical and nursing staff to provide care on the renal inpatient ward, the dialysis units and in the outpatient departments. This represents a diverse range of items, from generic items available throughout hospitals (such as urinary catheters, needles, syringes, gauzes and dressings) to highly specialised items required to provide care to patients with kidney disease (such as dialysis access catheters, peritoneal catheters, biopsy needles, dialysers and dialysis concentrates). Examples of the non-disposable items that are also occasionally purchased include stethoscopes and surgical-clip removers. DEFRA emissions factors have been applied to this activity data. Data for PGH and YDH haemodialysis units were not available (as these are privately run organisations) and were therefore estimated on a per patient basis from the DCH haemodialysis unit data.

Emissions data relating to the undertaking of radiological investigations are calculated from data on the number of radiological investigations undertaken by the Radiology Department at DCH on patients referred from the Dorset Renal Service. Activity data regarding the numbers of radiological investigations undertaken at RBH, PGH and YDH at the request of the Dorset Renal Service have been estimated. In the absence of data regarding the emissions arising from radiological investigations, an estimated figure of 0.1 kg CO_2eq per test has been assigned.

Emissions data relating to the collection and analysis of samples sent to the Pathology Department are calculated from data on the number of pathology investigations undertaken by the Pathology Department at DCH on patients referred from the Dorset Renal Service. Activity data regarding the numbers of pathology investigations undertaken at RBH, PGH and YDH at the request of the Dorset Renal Service have been estimated. In the absence of data regarding the emissions arising from radiological investigations, an estimated figure of 0.05 kg CO_2eq per test has been assigned. Multiple tests may be run from each sample collected.

Emissions data relating to paper and office supplies are calculated from the financial expenditure of the Dorset Renal Service on paper and office supplies (provided by the Procurement Department, DCH, with the exception of the data relating to the YDH haemodialysis component, which was estimated) and DEFRA emissions factors.

Emissions data relating to water are calculated from the volumes of water utilised for haemodialysis and DEFRA emissions factors.

Emissions data relating to food are calculated from the financial expenditure of the Dorset Renal Service on the different foodstuffs and beverages (provided by the Catering Department, DCH, and by the Procurement Department, DCH) and industrial sector emissions factors (from the National Statistics of Environmental Accounts).

Emissions data relating to the laundry services used by the Dorset Renal Service are calculated from measurements of the amount of laundry generated by patient activities (for example, one day as an inpatient, or one haemodialysis treatment), estimations of the distances travelled by this laundry (to and from private laundry companies), assumptions regarding the energy consumption of the washing and drying machines, and DEFRA emissions factors (for freight transport and purchased electricity consumption).

Emissions data relating to construction (for maintenance purposes only) are calculated from estimations derived from data provided by the DCH Estates Department detailing the expenditure per square metre on construction, and DEFRA emissions factors.

Emissions data relating to information technology are derived from data regarding the annual financial expenditure on information technology within each component of the Dorset Renal Service (derived from data detailing the amount of information technology equipment and assumptions regarding its rate of replacement) and the application of DEFRA emissions factors.

The components of the Dorset Renal Service each produce waste. The disposal of this waste contributes to the carbon footprint of the Dorset Renal Service. The model used in this study assigns the carbon embedded in products to the manufacturing process, and it is therefore included within the carbon footprint attributable to their procurement. It is important that this carbon is not then 'double counted' during the calculation of the emissions arising from the disposal of these products. Therefore, the 'end of life' carbon footprint has been calculated using the DEFRA emissions factors for waste treatment processes [DEFRA, 2009], as opposed to the sum of the 'end of life' and 'production' carbon footprints.

Waste is categorised as being either clinical or domestic waste. The disposal of the waste produced by the Dorset Renal Service is undertaken by the following three methods only; incineration, recycling, and landfill. Clinical waste is incinerated. The assumptions that have been made about energy recovery during incineration are detailed in the Assumptions section under the heading Waste Management. Domestic waste is further categorised by its disposal and constituents into the subgroups of: domestic waste that is incinerated; domestic waste that is recycled; domestic waste that is non-organic and sent to landfill; domestic waste that is organic (food) and sent to landfill; and domestic waste that is organic (non-food) and sent to landfill. The weights of the waste produced, within these different subgroups, by the different components of the Dorset Renal Service have been estimated from published data [Tudor et al., 2008; Askarian et al., 2004; Hoenich et al., 2005; Audit Commission, 1997] DEFRA emissions factors have been applied to these weights. A full account of the methodology for the determination of the emissions data for waste is provided in Appendix 2.

Emissions data relating to sanitation products are calculated from data on the financial expenditure by the Dorset Renal Service on sanitation products (provided by the Procurement Department, DCH, as expenditure through NHS Supply Chain and as non-stock purchases) and DEFRA emissions factors.

With the exceptions of the subsectors of pharmaceuticals and water, procurement data relating to the PGH and YDH haemodialysis services were limited as these are financed privately. Data for these services were estimated from the data collected for the DCH and RBH haemodialysis services on the basis of the number of treatments provided.

Boundary Setting: Inclusions and Exclusions

The boundary of the carbon footprint of the Dorset Renal Service has been set to include its component parts; namely the delivery of inpatient care, outpatient care, haemodialysis services, peritoneal dialysis services, transplantation services and administration, provided across the geographical sites (DCH, RBH, PGH, YDH and SMH).

Building Energy Use

The building energy use required to provide the aforementioned services at each site is included. The Dorset Renal Service delivers some care in facilities shared with other services. In such cases, only the building energy use attributable to the time for which the Dorset Renal Service uses these facilities is included.

Travel

Within each of these services, the carbon burden of staff, patient and visitor travel are included within the boundary.

Staff Travel

The travel of all staff working within the Dorset Renal Service was included; namely, ward and dialysis nursing staff (including auxiliary nursing staff and the clinical education team), doctors, dieticians, physiotherapists, occupational therapists, administrative staff, psychologists, phlebotomists, transplant nurse specialists, pre-dialysis nurse specialists, anaemia nurse specialists, dialysis technicians and social workers.

Although PAS2050 [British Standards, DEFRA, Carbon Trust, 2008] demands that the system boundary of the service should exclude GHG emissions associated with the travel of employees to and from their normal place of work, this report includes the commuting travel of all staff (as well as their business travel) in order to maintain consistency with the NHS England Carbon Footprinting Study [Sustainable Development Commission, 2008]. For those staff whose work was not exclusively based within the Dorset Renal Service (for example, psychologists), inclusion of their commuting travel was limited to those days in which they undertook any work on behalf of the Dorset Renal Service.

Patient Travel

Although PAS2050 [British Standards, DEFRA, Carbon Trust, 2008] demands that the system boundary of the service should exclude GHG emissions associated with the travel of consumers (in this case, patients) to and from the point of service use, this report includes patient travel in order to maintain consistency with the NHS England Carbon Footprinting Study [Sustainable Development Commission, 2008]. As such, all travel undertaken by patients to attend treatments or diagnostic investigations provided by, or organised by, the Dorset Renal Service has been included. This includes the return travel of inpatients to and from the ward, the return travel of patients attending either the ward or the hospital for day-case treatments (including, for example, iron infusions, blood transfusions, and temporary dialysis access procedures), the return travel of patients attending for the return travel of patients undergoing haemodialysis, the return travel of patients on peritoneal dialysis to their unit, the return travel of patients to outpatient appointments (including those with doctors, pre-dialysis nurse specialists, and transplant nurse specialists), the return travel of recently transplanted patients to outpatient appointments at the tertiary centre (SMH), and the return travel of patients attending for pathological or radiological investigations. Travel by patients to activities other than treatments or investigations, such as educational seminars, has not been included.

Visitor Travel

All travel undertaken by people visiting inpatients under the care of the Dorset Renal Service was included. The travel of people visiting patients who were not inpatients at the time was not included and was considered to be insignificant.

Transport

The transport of certain pathological specimens (including renal biopsy specimens) sent to other establishments to be processed was included.

Procurement

As the footprint includes both direct and indirect emissions, those emissions relating to the procurement of products and services contributing to the Dorset Renal Service are also included; namely, the procurement of pharmaceuticals, medical equipment, diagnostic investigations, paper and office supplies, the provision of food and drink to patients (inpatients and those receiving haemodialysis), construction (for maintenance purposes only), information technologies (computers, printers and fax machines only), laundry services, water, sanitation products, and the collection and treatment of waste.

Inter-departmental Overlap of Resource Use

The provision of clinical care to patients involves considerable overlap between different clinical services. For example, the overall care of a patient whose care is primarily delivered by the Dorset Renal Service may include diagnostic investigations performed by the Radiology Service. In such cases, the aspects of the secondary service which would be required to be in place even if patients from the Dorset Renal Service did not access the secondary service, have been excluded from the carbon footprint of the Dorset Renal Service, whilst those aspects of the service that are directly attributable to the patients from the Dorset Renal Service have been included.

Therefore, in the aforementioned example, the business and commuting travel of the staff working within the Radiology Service would be considered to lie outside of the boundary of the carbon footprint of the Dorset Renal Service. However, the travel of patients referred by the Dorset Renal Service to undergo investigations performed by the Radiology Service, the procurement of the materials required to undertake these particular investigations, and the building energy use consumed by the particular part of the department during the time taken to undertake them, have all been included.

Specific Boundaries Set within Procurement

Occupational Therapy & Physiotherapy

Occupational therapy is provided by one occupational therapist who can refer to local services where necessary. Only the occupational therapy provided by the therapist working within the Dorset Renal Service was included in the carbon footprint. Only physiotherapy provided by the physiotherapist affiliated to the Dorset Renal Service was included in the carbon footprint (this was limited to inpatient physiotherapy).

Waste

The disposal of all forms of waste produced by the Dorset Renal Service was included. These included clinical waste (which is incinerated off site), domestic waste which is recycled, and three forms of domestic waste that are sent to landfill; non-organic, organic (food) and organic (not food). The domestic waste that is recycled requires further comment as, since the recycling process is not undertaken within the Dorset Renal Service, the carbon recovered is realised outside of the boundary of this carbon footprint study. However, the DEFRA emissions factors for recycling have been applied to this waste (rather than to consider the disposal of this waste to have no impact upon the overall carbon footprint of the Dorset Renal Service) in order to maintain consistency in the approach to waste management.

Pharmaceuticals

The financial cost of the provision of pharmaceuticals to patients under the care of the Dorset Renal Service, for the treatment of both renal conditions and non-renal conditions, is shared between the Dorset Renal Service and the patients' Primary Care Trusts (PCT). For example, a medication may initially be prescribed by the Dorset Renal Service, but repeat prescriptions may be provided by the Primary Care Trust. Alternatively, a medication may be continually prescribed by the Dorset Renal Service. This is the case for medications to treat both renal and non-renal conditions, although medications prescribed by the Dorset Renal Service are more likely to be intended for the treatment of renal conditions. This report includes only those emissions associated with pharmaceuticals prescribed (and funded) by the Dorset Renal Service.

Surgery

The most common surgical procedures undertaken in conjunction with the Dorset Renal Service are dialysis access procedures and parathyroidectomy operations. These are undertaken at DCH and are integral to the care provided by the Dorset Renal Service. Carbon emissions relating directly to the surgical procedures (for example, building energy use in the operating theatre, and the procurement of surgical and anaesthetic equipment and pharmaceuticals), and to the peri-operative care of the patients (for example, building energy use on the inpatient ward), are considered to lie within the carbon footprint of the Dorset Renal Service. The same is true for renal transplantation which, although a less frequent procedure, is also integral to the care provided by the Dorset Renal Service but is undertaken elsewhere (SMH). Surgical procedures other than those described here lie outside of the boundary of the carbon footprint.

Universal Exclusions

The following sources of emissions were considered to lie outside of the boundary; the capital cost of machinery used repeatedly (including haemodialysis machines, see below); buildings; human inputs into the processes; food for staff; scientific research into renal medicine; staff training; water use other than that used in haemodialysis; business services; immaterial emissions sources (those anticipated to be less than 1% of total footprint).

Equipment Sterilisation

Although the Dorset Renal Service uses a very small amount of medical equipment requiring subsequent sterilisation in the hospital Sterilisation Services Department, the emissions relating to this process are considered highly unlikely to contribute more than 1% of the overall carbon footprint and were excluded from the carbon footprint of the Dorset Renal Service.

Machinery

The use of medical equipment, in the form of machinery, for the provision of dialysis is fundamental to a renal service. The manufacture of this machinery requires energy and results in GHG emissions. The machinery required for particular forms of peritoneal dialysis is used in a minority of patients, is loaned from the pharmaceutical company, and is used repeatedly. The machinery required for haemodialysis has a considerable lifetime (with guidance suggesting replacement at between 7 and 10 years, or between 25,000 and 40,000 hours of use [Renal Association, 2009]) and is used repeatedly. To maintain consistency with PAS2050 [British Standards, DEFRA, Carbon Trust, 2008], the GHG emissions arising from the production of capital goods used in the life cycle of the service have been excluded from the assessment of the GHG emissions of the service. However, emissions related to disposable consumables or pharmaceuticals used within this machinery are included. For haemodialysis, examples of these consumables include blood lines and synthetic fibre dialysers, which are made entirely from plastics. For peritoneal dialysis, examples include plastic tubing ('connecting kits') and dialysis fluids (six litre bags most commonly made from plastics and containing glucose-based electrolyte solutions).

Business Services

The Dorset Renal Service is responsible for a proportion of the work undertaken by the business services central to the running of the hospitals within which it is based. Such services will include Human Resources, Finances, Patient Liaison Services, Car Parking Services and Communications. The Dorset Renal Service will also be responsible for a proportion of the work undertaken by other 'non-business' services, such as Chaplaincy, Health and Safety, Portering Services, Library Services. However, accurate data regarding the contribution of these services to the overall emissions of the Dorset Renal Service are not available, but preliminary calculations from secondary data suggest that these sources are not likely contribute significantly. They have therefore been excluded from the calculation of the carbon footprint of the Dorset Renal Service. These lists are not exhaustive, but their inclusion is intended to provide a representation of services lying outside of the boundary of this report.

Accounting Period

This study calculates emissions for the Dorset Renal Service for the period April 1st 2008 to March 31st 2009, since that is the period for which full datasets are available. However, staff and patient travel surveys were undertaken in late 2009.

Assumptions

In order that this report is truly meaningful, and to facilitate replication, the assumptions made in the methodology, data collection and interpretation are outlined here.

Assumptions made regarding Building Energy Use

It has been assumed that the building energy use for a given floor space of each component of the Dorset Renal Service is comparable to the building energy use, for the same floor space, of the establishments in which each component is housed. It should be acknowledged that it is possible that the building energy use of certain components of the Dorset Renal Service (such as the haemodialysis units) may be greater than the building energy use averaged for the whole of the establishment in which they are housed. However, it is also possible that this may not be the case, as there are many other areas within the hospitals that might be anticipated to have high energy usage (for example, the cardiac catheterisation laboratory). The exception to this approach was the assumption that building energy use within surgical theatres was double that of the average building energy use of the hospital within which the theatres are sited. A full assessment was beyond the scope of this report. It has been assumed that the number of radiological investigations performed at the request of the Dorset Renal Service at sites other than the DCH Radiology Department is sufficiently small that the building energy use it entails will not contribute significantly to the carbon footprint of the Dorset Renal Service.

Assumptions made regarding Travel

Where travel was reported to have been undertaken by car, the DEFRA emissions factor for an 'average sized car using petrol or diesel' was used.

Where not otherwise specified, journeys by car and bus were assumed to have taken the shortest possible route by road.

In the absence of a means to calculate the distance of journeys reported to have been made by train, such distances were assumed to be comparable to the shortest route by road.

Where not otherwise mentioned, business travel by air was considered to have departed from Bournemouth Airport.

To maintain consistency with PAS2050 [British Standards, DEFRA, Carbon Trust, 2008], no uplift factor was applied for air travel.

Staff Travel (commuting and business)

Where data relating to phlebotomy staff were not captured by surveys, they were estimated using the following assumptions: a phlebotomy service is provided by a single phlebotomist and is available 6 days per week for inpatients and at all clinics; a phlebotomist is assumed to live 2 km from their place of work and to travel by car.

Where data relating to members of the surgical teams were not captured by surveys, they were estimated using the following assumptions: every theatre list requires one anaesthetist, one operating department assistant, one surgeon, one assistant surgeon, three theatre nurses and two recovery nurses, all of whom were assumed to live 10 km from their place of work and to travel by car.

Where data relating to domestic staff were not captured by surveys, they were estimated using the following assumptions: a cleaning service of one member of the domestic staff is available 7 days per week for inpatients, 6 days a week for haemodialysis services, 5 days a week for administration services, and at all clinics; peritoneal dialysis services are included within the haemodialysis services for these purposes; a member of the domestic staff is assumed to live 2 km from their place of work and to travel by car.

Patient Travel

With the exception of the data captured by surveys, it was assumed that all patients commenced all journeys from, and returned directly to, their own homes.

It was assumed that 75% of patients arriving and leaving the inpatient ward travelled by car and that the remaining 25% travelled by ambulance.

It was assumed that 90% of patients attending the ward for day case treatment travelled by car and that the remaining 10% travelled by ambulance.

It was assumed that patients receiving peritoneal dialysis would visit their department three times per year in addition to their routine outpatient clinic appointments. It was assumed that all travel was by car.

It was assumed that all travel by patients to attend outpatient clinics with the pre-dialysis nurse specialist, the transplant nurse specialist, or at the SMH clinic in the weeks following transplantation, was undertaken by car.

It was assumed that all patient travel to attend for iron infusions was undertaken by car.

It was assumed that two thirds of all patients attending outpatient appointments would be required to undergo a blood test prior to this, and that each of these patients would travel 2 km each way by car to attend for this.

Visitor Travel

No data regarding the travel of visitors were available. It was assumed that only inpatients received visitors. It was assumed that the 14 beds on the inpatient ward were occupied at all times. It was assumed that each inpatient would receive one visitor every other day. It was assumed that each visitor undertook a 40km round trip, reflecting the fact that the inpatient unit covers a large geographical region. In keeping with the National Transport Survey 2006 for distances of this length, it was assumed that 84.3% of these journeys were made by car, 9.6% of these journeys were made by bus, 3.6% of these journeys were made by rail, 0.6% of these journeys were made by active transport, and 1.9% of these journeys were made by other means [Department for Transport, National Statistics, 2006].

Assumptions made regarding Procurement

Pharmaceuticals

No assumptions have been made regarding pharmaceuticals.

Medical Equipment

In the absence of specific data, the financial expenditure on medical equipment for the YDH and PGH haemodialysis services was assumed to be the same, per patient, as for the DCH haemodialysis service.

Pathology Investigations

In the absence of specific data, an assumption has been made that the emissions associated with a pathological investigation of any kind (including the sampling procedure and the analysis of the specimen) is 0.05 kg CO_2eq.

Radiology Investigations

In the absence of specific data, an assumption has been made that the emissions associated with undertaking any radiological investigation has been assumed to be 0.1 kg CO_2eq. This relatively small value is intended to reflect the small amount of materials consumed in producing radiological images that are viewed electronically.

Paper

It was assumed that paper was purchased in reams of 5OO sheets. In order to allow the use of DEFRA emissions factors (which, for paper, relate to financial cost), it was assumed that each ream cost £5.

Food

The food consumed 'per bed' per year within DCH has been assumed to be representative of the food consumed by the inpatients under the care of the Dorset Renal Service.

Information Technology

It has been assumed that emissions derived from information technology relate only to the equipment, and that this is limited to computers, printers and fax machines. It has been assumed that these items are replaced every three years. It has been assumed that the financial costs of replacing a computer, a printer and a fax machine, are £500, £75 and £100 respectively.

Water

Only the water used to provide haemodialysis has been included in the analysis on the assumption that all other water use is minimal in comparison.

Laundry Services

DCH has a very small laundry department onsite but contracts out the majority of the hospital's laundry requirements to a private company. The other sites at which the Dorset Renal Service provides patient care have no laundry facilities on site. It has therefore been assumed that all linen used by the Dorset Renal Service is laundered off-site, and that this occurs at the nearest facility of the company with whom the relevant hospital has a laundry contract. It has been assumed that the laundry travels in rigid, diesel, heavy goods vehicles which run at the United Kingdom average capacity. As the Dorset Renal Service laundry forms a component of the local site's overall laundry burden, it has been assumed that the number of journeys made is equivalent to the total weight of laundry produced per year, divided by the maximum capacity of the vehicles used. In the absence of more accurate data, it has been assumed that the washing and drying machines have energy efficiencies, per kg load, equivalent to that of standard domestic machines.

Construction

In the absence of specific data, the financial expenditure on construction, for a given floor space, of the components of the Dorset Renal Service has been assumed to be similar to that of the DCH site.

Sanitation

In the absence of specific data, the financial expenditure on sanitation, for a given floor space, of the components of the Dorset Renal Service has been assumed to be similar to that of the DCH site.

Waste Management

A number of assumptions were made regarding the production and disposal of waste. Their context is explained in detail in Appendix 2.

1. It was assumed that, on the inpatient ward and in the dialysis facilities, 40% of all waste was clinical waste and that the remaining 60% was domestic waste. It was assumed that, in the outpatients departments, only 20% of all waste was clinical waste and the remaining 80% was domestic waste. In the administration areas it was assumed that all waste was domestic waste.

2. It was assumed that all clinical waste was incinerated. It was assumed that the carbon burden resulting from the disposal to landfill of any ash formed from incineration would be negligible. It was assumed that no energy recovery would be feasible from the incineration of clinical waste (as fuel fired incineration would be required to establish the high temperatures needed to ensure safe disposal of the waste, and given that the contents of clinical waste would be unlikely to burn without fuel fired incineration). In line with these considerations, it was also assumed that the DEFRA emissions factors – which do not relate specifically to incineration of clinical waste – would underestimate the emissions arising from the process, and therefore the highest quoted

emissions factor for incineration was universally applied to the different constituents of the clinical waste.

3. On the basis of peer reviewed publications [Askarian et al., 2004; Olko & Winch, 2002] it has been assumed that segregation at source within the healthcare setting is imperfect, and that 25% of all waste entering the clinical waste stream is in fact domestic waste, which is therefore incinerated.

4. It was assumed that 30% of all domestic waste would be recycled. It has been assumed that all recycling is 'closed loop recycling' whereby the material does not change and is used again for the same purpose.

5. It was assumed that the remaining 70% of domestic waste would go to landfill.

6. On the basis of peer reviewed publications [Askarian et al., 2004; Olko & Winch, 2002], it was assumed that 60% of the domestic waste going to landfill would be organic waste and that the remaining 40% would be non-organic. In the inpatient ward and administration areas, it was estimated that 25% of the organic waste would be food waste. In the other areas, it was estimated that only 8% of the organic waste would be food waste.

Emissions Factors

The Choice of Emissions Factors

The gold standard methodology for the assessment of the production of GHGs associated with a process or product is the recording of the emissions at source through continuous emissions monitoring. However, this is an impractical approach for most carbon footprint assessments. Instead, emissions factors (also referred to as carbon conversion factors or GHG conversion factors) may be applied to activity data to calculate emissions data. Emissions factors are available from a number of different sources, including the IPCC, DEFRA and the United Kingdom Emissions Factor Database. The different emission factor databases include emission factors for different products and materials. Furthermore, for a given material, product or process, there may be considerable variation in the emission factors quoted by the different databases. There are a number of reasons for this variation. Firstly, it may be the result of the differing conditions in which the materials or products may be manufactured, used and disposed of (for example, practice will vary on a regional basis and variation between emissions factors developed in differing countries is common). Secondly, it may relate to the differing scientific approaches used in the development of the emissions factors. Thirdly, the variation may originate from the use of differing system boundaries; input-output data typically have wider boundaries than process data. It is important that those emissions factors most appropriate to the intended purpose are selected in order that the assessment of a carbon footprint is as accurate as possible. Also, the emissions factors used should be clearly stated in the report in order that the carbon footprint can be appropriately interpreted and replicated.

The Emissions Factors for Medical Equipment and Pharmaceuticals

The preliminary results of this study suggested that the emissions arising within the supply chain and attributable to the procurement of medical equipment and pharmaceuticals were likely to contribute a substantial proportion of the carbon footprint of the Dorset Renal Service. It was therefore considered particularly important that the emissions factors applied to activity data within these subsectors were as accurate and appropriate as possible. However, emissions factors for the procurement of medical equipment and pharmaceuticals were identified in only two databases; emissions factors provided by the National Statistics of Environmental Accounts were used in the assessment of the carbon footprint of NHS England and are listed in the report [Sustainable Development Commission, 2008], whilst DEFRA also provides supply chain emissions factors for these subsectors [DEFRA, 2009]. Of further concern was the fact that, not only did considerable variation exist between the emission factors quoted by these two databases for the two subsectors (Table 3), but both databases quoted absolute figures without confidence intervals.

Table 3. The emissions factors available for the procurement of pharmaceuticals and medical equipment.

Emissions Factor Database	Emissions Factor for Pharmaceuticals (kg CO_2 per £)	Emissions Factor for Medical Equipment (kg CO_2 per £)
National Statistics of Environmental Accounts [Sustainable Development Commission, 2008]	0.20	0.24
DEFRA [DEFRA, 2009]	0.62	0.45

As it was not clear which emissions factors were the most appropriate for the assessment of the carbon footprint of the Dorset Renal Service, consideration was first given to the methodologies underpinning their development.

The DEFRA emissions factors for supply chain emissions are provided by the Centre for Sustainability Accounting in York. These factors are based on an input-output economic model, which describes in monetary terms how the goods and services produced by different sectors of the economy are used by other sectors to produce their own output. These monetary accounts are linked to information about the GHG emissions of different sectors of the economy. By using the input-output model, these emissions are then attributed to the monetary transactions taking place in the economy. The result is an estimate of the total upstream emissions associated with the supply of a particular product group. As the input-output tables used for this exercise were in 2004 basic prices (i.e. net of taxes on products and distributors' margins), DEFRA advises that it may be appropriate to take subsequent price changes into account when using their factors.

Emissions arising from the supply chain of NHS England were calculated by undertaking an input-output analysis of the NHS [Sustainable Development Commission, 2008]. This used an input-output table comprising of 178 industrial sectors, which was provided by Stockholm Environment Institute. The input-output analysis was combined with GHG emissions provided by the National Statistics of Environmental Accounts (http://www.statistics.gov.uk/STATBASE/ssdataset.asp?vlnk=9640). The emissions factors are listed in the report [Sustainable Development Commission, 2008]. The same emissions factors for pharmaceuticals and medical equipment were subsequently used in an assessment of the carbon footprint of clinical trials [Lyle et al., 2009].

Therefore it appeared that the two sets of emissions factors had been developed using similar methodologies. Given that they were both based upon economic input-output tables using 2004 prices, it was assumed that the use of both sets of emissions factors would be susceptible to the same degree of error resulting from changes in the structure and emissions intensity of the supply chain since the time of the production of the emissions factors. Further analysis of the methodologies was considered to be unlikely to ascertain which methodology had produced emissions factors most applicable to the requirements of this study.

Instead, the problem was approached from the other direction, and an attempt was made to ascertain the carbon burden of medical equipment using physical rather than economic data. Firstly, a sub-group of the medical equipment subsector of procurement within the Dorset Renal Service was identified (namely, the purchase of medical equipment, for the renal inpatient ward, from NHS Supplies, during the accounting period). These data contained the orders placed, for differing quantities, for a total of 182 different items of medical equipment. Next, for each different item purchased, the following data were collected or directly measured: the number of the items purchased during the accounting period, the weight of each item, and the material from which the item was predominantly made. Finally, emissions factors relating to this material were then applied to convert these weights to CO_2 emissions. These emissions factors were taken from an independent database, the Inventory of Carbon and Energy (ICE, version 1.6a) [Hammond & Jones, 2008]. Produced by the University of Bath, this is an inventory of embodied carbon for building materials, and the data are derived from secondary resources in the public domain, such as journal articles, life cycle assessments and conference reports. The result of this calculation, the total CO_2 emissions attributable to the procurement of medical equipment for the inpatient ward from NHS Supplies, was then compared against data calculated from the financial expenditure on this sub-group of the medical equipment subsector and the emissions factors sourced from both DEFRA and the National Statistics of Environmental Accounts. The results are shown in the Table 4.

Table 4. The variation in the CO_2 emissions attributable to the procurement of medical equipment for the inpatient ward when determined using different emissions factors.

Database from which the emissions factors are taken.	CO_2 emissions resulting from the procurement of medical equipment for the inpatient ward from NHS Supplies between 1/4/08 and 31/3/09. (kg CO_2)
ICE 1.6a [Hammond & Jones, 2008]	11,300
DEFRA [DEFRA, 2009]	14,487
National Statistics of Environmental Accounts [Sustainable Development Commission, 2008]	7,726

These calculations therefore suggested that the DEFRA emissions factor overestimated the emissions attributable to the procurement of medical equipment, whilst the emissions factor provided by the National Statistics of Environmental Accounts underestimated it. However, it is important to note that the calculations relate only to the components of the products, and do not include other aspects of their life-cycle such as transportation to factories or users.

A comparison has been made of the use of different emissions factors for the procurement of items of medical equipment for the inpatient ward. The items in question were those typically found on a renal ward and, as such, the majority of these items were not specific to the provision of renal care, but would be found on the majority of inpatient wards. Were a similar assessment of the items procured for the provision of the haemodialysis or peritoneal dialysis services (rather than for the provision of inpatient care to patients with renal conditions) to have been undertaken, it is likely that the results obtained using emissions factors from the ICE database would be closer to those derived from the application of DEFRA emissions factors than to those arising from the use of emissions factors quoted by the National Statistics of Environmental Accounts. In short, the carbon burden of the medical equipment specific to the provision of RRT is likely to be at the higher end of the spectrum. Whilst the assessment of this hypothesis through the undertaking of a similar assessment on dialysis equipment would be problematic as many more of the items are composed of multiple materials, it is supported by carbon footprinting work undertaken independently within the renal industry. The carbon footprint of a one litre intravenous fluid bag (Viaflo, produced by Baxter Healthcare) has been calculated at 0.613 kg CO_2eq (personal communication with David Jiggins, Sustainability & Producer Responsibility Coordinator, European EHS Affairs, Baxter Healthcare Ltd, by email, April 29th, 2010). This cradle to grave assessment included the embodied emissions of the components and packaging, transportation of components and packaging from manufacturers to Baxter manufacturing sites, Baxter premises activities (rolled stock film production, fill up and sterilisation), transportation of finished products to the Baxter storage and distribution centre, delivery of finished products to customer base and final disposal of the products. The current list price for a one litre Viaflo bag of sodium chloride is £1.27. The carbon intensity is therefore 0.48 kg CO_2eq per £, which is very similar to the figure quoted by DEFRA of 0.45 kg CO_2eq per £ [DEFRA, 2009].

Another point of note is that, although the emissions factors used in the NHS England Carbon Footprinting Study commissioned by the NHS Sustainable Development Unit (SDU) were provided by the National Statistics of Environmental Accounts, more recent work by the NHS SDU has used the DEFRA emissions factors for the procurement of medical equipment and pharmaceuticals [Eastern Region Public Health Observatory, 2010].

The emissions factors quoted by DEFRA for the procurement of medical equipment were therefore used in this study. However, the impact upon the overall carbon footprint of the Dorset Renal Service of using the emissions factors provided by the National Statistics of Environmental Accounts is considered in greater detail in the discussion (under the heading, 'Uncertainty of the Results'). The use of these two factors demonstrates the variation, and also the potential error, inherent in this form of environmental accounting.

Aside from the belief that the DEFRA emissions factors more accurately reflect the emissions attributable to the procurement of medical equipment specific to renal healthcare, the choice has also been influenced by the wider recognition of, and ease of access to, the DEFRA emissions factors.

The sub-sector of pharmaceuticals does not lend itself to a similar assessment of the emissions factors quoted by the two databases. The emissions factor quoted by DEFRA for this sub-sector was therefore used in order to maintain consistency.

The Emissions Factors for Waste Management

The uncertainty that exists with regard to the respective carbon burdens of the disposal of waste by landfill and incineration was described in Chapter 2. Furthermore, DEFRA emissions factors for the incineration of different materials do not account specifically for the incineration of clinical waste, a process which is typically undertaken at higher temperatures than other forms of incineration. However, the emissions factors provided by DEFRA represent the most appropriate range of factors for the purposes of this study, as they address the disposal of different types of waste by the three main routes of disposal employed within healthcare. Therefore, to reflect the increased emissions that are likely to result from the incineration of clinical waste, the highest available emissions factor for incineration was applied to each of the constituents.

The Emissions Factors used in this Study

The emissions factors used in the assessment of the carbon footprint of the Dorset Renal Service are provided in Tables 5-8.

Table 5. The emissions factors applied to building energy use activity data.

Source of Energy	**Emissions factor to convert to GHG emissions (kg CO_2eq per kWh) [a]**
Electricity	0.54418
Heating / hot water from gas	0.18396
Heating / hot water from oil	0.27652
Heating / hot water from coal	0.33920

[a] Emissions factors from DEFRA (2009) [DEFRA, 2009].

Table 6. The emissions factors applied to staff, patient and visitor travel, and freight transport, activity data.

Travel Modality	Emissions factor to convert to GHG emissions ($kg\ CO_2eq$ per km) [f]
Active travel (walking, cycling)	0.0
Car [a]	0.20487
Bus [b]	0.10462
Train [c]	0.06113
Air Travel (domestic) [d]	0.17283
Freight Transport [e]	0.80201

[a] This emissions factor refers to an average car, running on diesel or petrol, and undertaking average journey lengths, within the United Kingdom.

[b] This emissions factor refers to an average public bus in the United Kingdom.

[c] This emissions factor refers to an average emission passenger diesel or electric train in the United Kingdom.

[d] This emissions factor was used as the vast majority of all air travel undertaken was using domestic flights. Although suggested by the DEFRA guidance [DEFRA,2009], an uplift factor was not applied to the distance prior to the use of this emissions factor in order to maintain consistency with PAS2050 [British Standards, DEFRA, Carbon Trust, 2008].

[e] This emissions factor, which refers to the average rigid (non-articulated) heavy goods vehicle in the United Kingdom, was used to calculate the emissions relating to the transport of laundry to privately run, off site, laundry services.

[f] Emissions factors from DEFRA (2009) [DEFRA, 2009].

Table 7. The emissions factors applied to procurement activity data.

	Source of emissions factor	Emissions factor to convert to GHG emissions
Pharmaceuticals	DEFRA [DEFRA, 2009]	0.81 kg CO_2eq per £
Medical Equipment	DEFRA [DEFRA, 2009]	0.57 kg CO_2eq per £
Diagnostic Investigations (Pathology)		No emissions factor available. An individual blood test has been assigned a nominal carbon cost of 0.05 kg CO_2eq.
Diagnostic Investigations (Radiology)		No emissions factor available. An individual blood test has been assigned a nominal carbon cost of 0.1 kg CO_2eq.
Paper and Office Supplies	DEFRA [DEFRA, 2009]	1.30 kg CO_2eq per £
Food and Catering	National Statistics of Environmental Accounts [Sustainable Development Commission, 2008]	
Dried goods		0.49 kg CO_2eq per £
Frozen, chilled, dried		0.49 kg CO_2eq per £
Bread		0.35 kg CO_2eq per £
Dairy		0.92 kg CO_2eq per £
Fish		0.58 kg CO_2eq per £
Fresh Fruit & Vegetables		0.53 kg CO_2eq per £
Potatoes		0.53 kg CO_2eq per £
Meat		0.77 kg CO_2eq per £
Coffee		0.32 kg CO_2eq per £
Sugar		0.80 kg CO_2eq per £
Biscuits		0.35 kg CO_2eq per £
Paper Cups		0.60 kg CO_2eq per £
Construction	DEFRA [DEFRA, 2009]	0.54 kg CO_2eq per £
Information Technology	DEFRA [DEFRA, 2009]	0.58 kg CO_2eq per £
Water	DEFRA [DEFRA, 2009]	0.276 kg CO_2eq per cubic metre of water
Sanitation Products	DEFRA [DEFRA, 2009]	0.80 kg CO_2eq per £

Table 8. The emissions factors applied to waste collection, treatment and disposal activity data.

Waste Disposal Method	Waste Constituent	kg CO_2eq emitted per tonne of waste constituent [a]
INCINERATION	Paper	1800 [b]
	Plastics	
	Cardboard	
	Glass	
	Other waste	
	Metal	
RECYCLING	Paper	-713
	Plastics	-1500
	Cardboard	-713
	Glass	-315
	Other waste	-259
	Metal	-9000
LANDFILL	Paper	550
	Plastics	40
	Cardboard	550
	Glass	10
	Other waste	81
	Metal	10
	Organic waste (food)	365
	Organic waste (non food)	230

[a] Emissions factors from DEFRA (2009) [DEFRA, 2009].

[b] DEFRA emissions factors for incineration of different materials do not account for the incineration of clinical waste, which must be undertaken at higher temperatures. To reflect the increased emissions that are likely to result from the incineration of clinical waste, the highest available emissions factor for incineration was applied to each of the constituents.

Data Accuracy

When calculating a carbon footprint, measures should be taken to ensure that all input, output and waste streams are accounted for and that no 'double counting' of emissions has occurred. Whilst a common approach to this is to undertake a 'mass balance', the mix of economic and physical data collected in this study renders this approach impractical. This problem, which is relatively common when calculating the carbon footprint of a service rather than a product, may be surmounted by performing an activity based assessment. For a given activity, all processes and materials flowing into and out of that activity stage must be analysed for their GHG emissions. When calculating the carbon footprint of a healthcare service, as is the case in this study, an activity based assessment might best be undertaken at the level of the individual patients. Unfortunately, the heterogeneity of patient demographics and uptake of activities within the service presents problems with data availability and again renders the approach impractical for this study. The authors are aware of the issues pertaining to the double accounting of emissions and all reasonable efforts have been made to overcome them during the design and data collection stages of this study.

The variables identified by the authors as being the greatest potential sources of error are the emissions factors used for medical equipment and pharmaceuticals. The methodology used to ensure that the most accurate emissions factors were used for these subsectors has been previously described (under the heading, 'The Choice of Emissions Factors') and its potential impact is discussed later (under the heading, 'Uncertainty in the Results').

Results

The Carbon Footprint of the Dorset Renal Service

Primary Sector Results

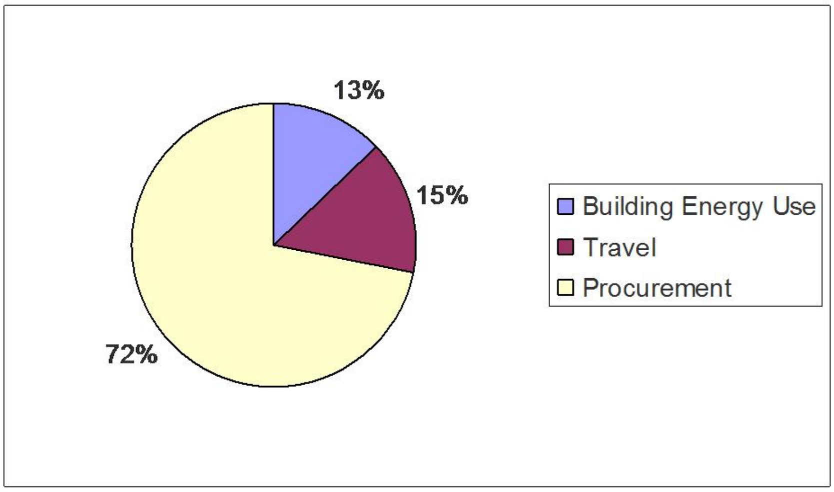
The total emissions associated with the Dorset Renal Service comprise the sum of emissions from three primary sectors; building energy use, travel and procurement. The calculated emissions for these primary sectors are given below in Table 9 and displayed in Figure 2.

Table 9. Primary Sector Breakdown of the Carbon Footprint of the Dorset Renal Service.

Sector	GHG Emissions (kg CO_2eq)	% of GHG Emissions [a]
Building Energy Use	381,331	13%
Travel	461,886	15%
Procurement	2,163,403	72%
Total Dorset Renal Service Emissions (Kg)	3,006,620	100%
Total Dorset Renal Service Emissions (tonnes)	3,007	100%

[a] Values rounded to nearest 1%.

Figure 2. Primary sector breakdown of the GHG emissions of the Dorset Renal Service.



Sub-sector Results

The three primary emissions sectors have constituent sub-sectors. The calculated emissions for these sub-sectors are given in Table 10 and displayed in Figures 3, 4a and 4b.

Table 10. Sub-sector breakdown of the GHG emissions of the Dorset Renal Service.

Sector	Subsector	GHG Emissions (kg CO_2eq)	%age of GHG Emissions
Building Energy Use		381,331	12.68
	Total for Building Energy Use	**381,331**	**12.68**
Travel	Staff Commuting	143,774	4.78
	Staff Business	17,774	0.59
	Patient travel	279,293	9.29
	Visitor travel	20,448	0.68
	Other travel	598	0.02
	Total for Travel	**461,886**	**15.36**
Procurement	Pharmaceuticals	1,043,660	34.71
	Medical Equipment	752,862	25.04
	Diagnostics (Radiology)	209	0.01
	Diagnostics (Pathology)	4,720	0.16
	Paper	9,401	0.28
	Food	6,933	0.23
	Laundry Services	14,070	0.47
	Construction	31,692	0.94
	IT	5,908	0.18
	Water	6,169	0.20
	Sanitation Products	1,954	0.06
	Waste	291,125	9.68
	Total for Procurement	2,163,403	**71.95**
Overall Totals	Kg	3,006,620	100%
	Tonnes	3,007	100%

Figure 3. Procurement subsector GHG emissions within the Dorset Renal Service.

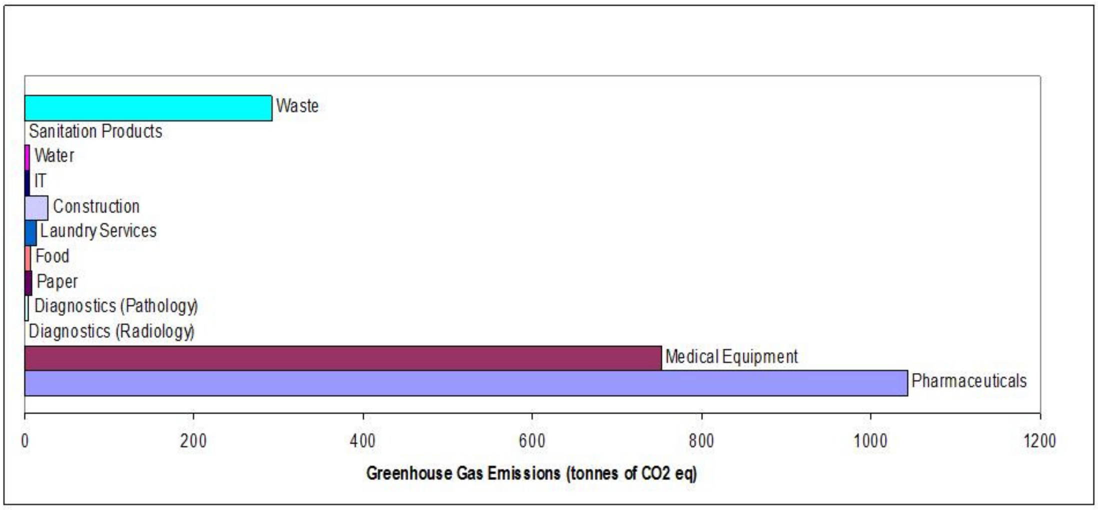


Figure 4a. Travel subsector GHG emissions within the Dorset Renal Service.

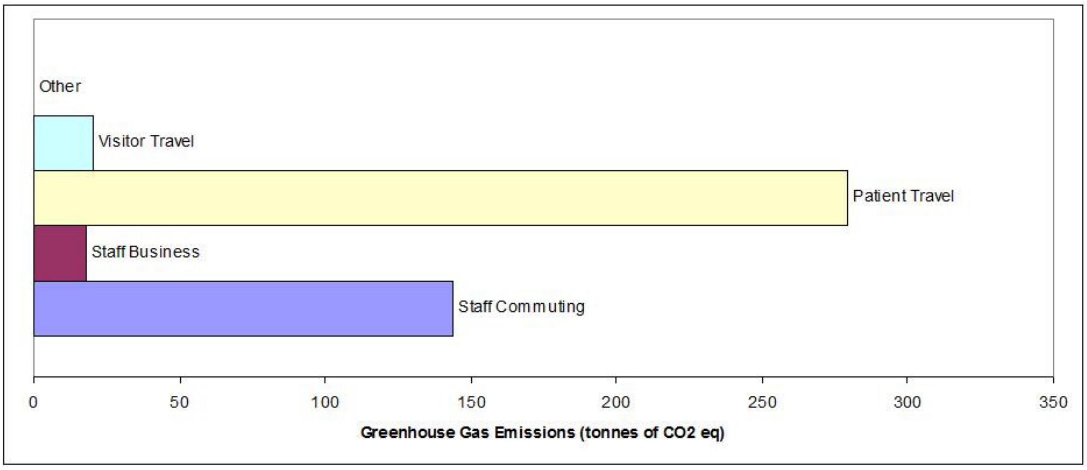
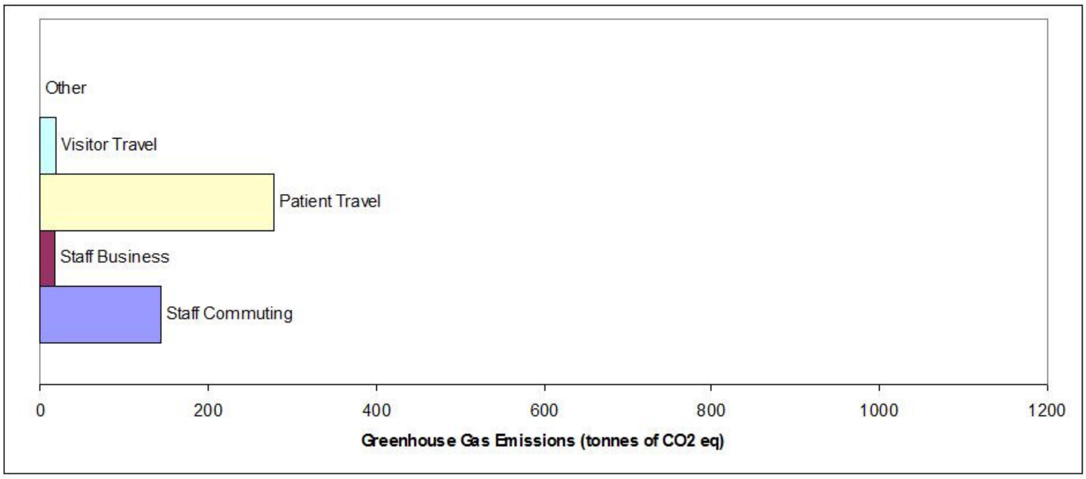


Figure 4b. Travel subsector GHG emissions within the Dorset Renal Service (using a scale consistent with that used in Figure 3).



Carbon Emissions per Unit of Healthcare Activity

Table 11: GHG emissions directly attributable to the provision of haemodialysis and peritoneal dialysis within the Dorset Renal Service. Due to the aggregated nature of some of the activity data, it is possible that these figures underestimate the true contributions of these components of the Dorset Renal Service.

Sector	GHG Emissions attributable to the provision of haemodialysis and peritoneal dialysis (kg CO_2eq)	GHG Emissions expressed as a % of the total emissions of the Dorset Renal Service
Building Energy Use	278,398	9.3%
Travel [a]	507,225	16.9%
Procurement (excluding waste)	917,552	30.5%
Waste	262,128	8.7%
Total	**1,965,305**	**65.4%**

[a] Return travel by patients to attend haemodialysis treatments produces 173,248 kg CO_2eq, which represents 34.2% of the overall travel emissions, and 5.76% of the overall emissions, of the Dorset Renal Service.

Table 12: GHG emissions attributable to the provision of outpatient appointments within the Dorset Renal Service. These values should be considered to be indicative only, as they are calculated from aggregated activity data.

Sector	**GHG Emissions attributable to the provision of outpatient care within the Dorset Renal Service (kg CO_2eq)**	**GHG Emissions expressed as a % of the total emissions of the Dorset Renal Service**
Building Energy Use	15,992	0.53%
Total Travel	104,490	3.48%
Staff commuting travel	*22,157*	*0.74%*
Staff business travel	*4,144*	*0.14%*
Patient travel	*78,189*	*2.6%*
Procurement (excluding waste)	45,848	1.52%
Waste	5,641	0.18%
Total	**171,971** [a]	**5.72%**

[a] Within the Dorset Renal Service, a total of 171,971 kg CO_2eq result from approximately 7,800 appointments per year. This equates to an indicative carbon burden of 22 kg CO_2eq per outpatient appointment.

Table 13: GHG emissions attributable to the provision of inpatient care within the Dorset Renal Service. These values should be considered to be indicative only, as they are calculated from aggregated activity data.

Sector	**GHG Emissions attributable to the provision of inpatient care within the Dorset Renal Service (kg CO_2eq)**	**GHG Emissions expressed as a % of the total emissions of the Dorset Renal Service**
Building Energy Use	63,432	2.1%
Total Travel	121,306	4.0%
Staff commuting travel	*77,390*	*2.6%*
Staff business travel	*7,446*	*0.2%*
Patient travel	*17,620*	*0.6%*
Visitor travel	*18,850*	*0.6%*
Procurement (excluding waste)	587,153	19.5%
Waste	52,125	1.7%
Total	**824,016** [a]	**27.4%**

[a] Within the Dorset Renal Service, a total of 824,016 kg CO_2eq result from an estimated 5,110 bed days per year. This equates to an indicative carbon burden of 161 kg CO_2eq per bed day.

An Estimation of the Carbon Footprint of the Provision of Renal Services across England

The carbon footprint of the Dorset Renal Service is 3,006 tonnes of CO_2eq per annum. The application of an uplift factor of 1.234567 to this figure provides a value (3,711 tonnes of CO_2eq per annum) that was considered to be representative of the carbon footprint of a typical renal service in England. The Renal Registry lists 53 'hub' units co-ordinating adult renal services across England. The total carbon burden of the delivery of renal healthcare to adults across England is therefore estimated to be 196,688 tonnes of CO_2eq per annum. This represents 0.93% of the 21.28 million tonnes of GHG emissions attributed to NHS England [Sustainable Development Commission, 2008].

Discussion

The Carbon Footprint of the Dorset Renal Service

The total GHG emissions of the Dorset Renal Service in 2008 have been calculated to be 3,007 tonnes CO_2eq. This is almost certainly an underestimate of the true value as the process analysis approach predisposes to truncation errors.

Carbon reduction strategies often focus on building energy use. However, this contributes only 13% of the overall emissions of the Dorset Renal Service. This is considerably lower than the 22% contribution that building energy use made to the NHS England carbon footprint [Sustainable Development Commission, 2008]. This discrepancy is probably the result of two factors. Firstly, whilst the overall building energy use attributable to business services was accounted for in the NHS England study, the study excluded the proportion of building energy use attributable to the hospital business services that might reasonably have been allocated to the carbon footprint of the Dorset Renal Service (as it was not quantifiable). Secondly, and more importantly, the emissions resulting from the high level of procurement of pharmaceuticals and medical equipment within the Dorset Renal Service will have impacted upon the balance of the contributions of the different primary sectors. Overall, the results of this study support the assertion, proposed in the introduction to Chapter 2, that measures to reduce building energy use, although important, should form only part of strategies intended to reduce the carbon footprint of renal healthcare.

Similarly, even with the inclusion of staff commuting travel, overall travel emissions contribute only 15% of the carbon footprint of the Dorset Renal Service (a figure very similar to their contribution of 16% to the NHS England carbon footprint [Sustainable Development Commission, 2008]). Patient travel contributes 60% of the overall travel emissions. That this is greater than the contribution (44%) made by patient travel to the overall travel emissions of NHS England is not unexpected given that the most common form of RRT, ICHD [Byrne, Steenkamp et al., 2010], requires that patients undertake return journeys to their dialysis facility three times per week. However, the two figures are not truly comparable as patient travel emissions associated with hospital transport services (as opposed to private travel) are not included in the patient travel emissions in the NHS England study.

The discrepancy between the contribution of patient travel emissions to the carbon footprint of the Dorset Renal Service (60% of overall travel emissions) and to that of NHS England (44%) is lessened by the provision of dialysis at satellite units, which reduce the travel undertaken by dialysis patients. In this regard, the Dorset Renal Service is typical in that it has 3 such units (the mean number of satellite units per hub unit in England is 3.02, range 0 – 10, calculated using data from the Twelfth Annual Renal Registry Report [Byrne, Steenkamp et al., 2010]). The contribution of dialysis-related patient travel is of interest. Whilst patient travel to haemodialysis is responsible for 173 tonnes of CO_2eq, which represents 34% of overall travel emissions, this amounts to only 6% of the overall emissions of the Dorset Renal Service. Given that the Dorset Renal Service provides ICHD in a relatively rural population, and to a higher than average proportion of the patients requiring RRT within that area (49.8%, mean within England = 39.6%, range = 7.2 – 72.2%, calculated using data from the Twelfth Annual Renal Registry Report [Byrne, Steenkamp et al., 2010]), these results indicate that, whilst necessary, initiatives to reduce the emissions associated with dialysis related patient travel are unlikely to impact significantly upon the overall carbon footprint of renal services.

A key finding of this study was that procurement provides the remaining 72% of the overall emissions of the Dorset Renal Service, a proportion which is in keeping with a service sector organisation (rather than one within the manufacturing industry). Pharmaceuticals and medical equipment generate 60% of all emissions arising from the Dorset Renal Service. This is double the contribution of these subsectors to the NHS England carbon footprint, and represents 83% of all procurement emissions of the Dorset Renal Service. This figure would have been greater still had not only those medications prescribed by clinicians working in the Dorset Renal Service been included in the analysis, but also the many repeat prescriptions of medications originally commenced by the Dorset Renal Service that are subsequently provided by Primary Care.

However, such an all-encompassing boundary would have required an individual assessment of whether to include each individual medication prescribed to each individual patient. Not only would this have been impractical, difficulties would also have been encountered when determining a consistent approach to deciding which of a patient's medications should be considered to be part of the treatment of a patient's renal condition, as the roles of similar medications may vary on a patient by patient basis.

As has been discussed in the earlier chapters, the most common technologies currently used to provide haemodialysis result in renal services using vastly more water than most other clinical specialties. The Dorset Renal Service uses approximately 22 million litres of mains water per year in the provision of haemodialysis alone. However, this water use produces only 6 tonnes of GHG emissions and contributes less than 1% of the overall carbon footprint of the Dorset Renal Service. These figures illustrate that, whilst water is a finite natural resource, the environmental arguments for its conservation are based predominantly around preventing the depletion of natural resources rather than reducing carbon emissions. As such, an ecological footprint might confer a greater weighting upon the contribution of the water use to the environmental impact of a renal service than a carbon footprint study such as this. It should also be noted that, whilst this volume of water use is far greater than in other clinical specialties, it pales into insignificance when compared to the use of water in agriculture and is far less than that used in the laundry departments of many hospitals.

The contribution of waste (10%) to the overall emissions of the Dorset Renal Service is considerably higher than its contribution to the carbon footprint of NHS England (3%) [Sustainable Development Commission, 2008], although both studies assigned the carbon embedded at the time of manufacture to the procurement of the products rather than to their disposal. The high contribution of waste to the carbon footprint of the Dorset Renal Service perhaps reflects the fact that the increasing availability of dialysis has been dependent upon single-use, pre-packaged products, with both peritoneal and haemodialysis producing large amounts of clinical waste [Hoenich et al., 2005]. Disposal of clinical waste is most commonly by incineration, to which a higher carbon burden than disposal to landfill is attributed by the DEFRA emissions factors [DEFRA, 2009].

The subsector of food makes a minimal contribution to the carbon footprint of the Dorset Renal Service, primarily because food is only generally provided to patients on the acute ward (who represent a tiny proportion of the overall patients accessing the Dorset Renal Service).

The Carbon Footprint of the Provision of Renal Healthcare to Adults across England

The total carbon burden of the delivery of renal healthcare to adults across England is estimated to be 196,688 tonnes of CO_2eq per annum. This equates to 0.93% of the overall GHG emissions attributable to NHS England, and 2.16% of the 9.1 million tonnes of CO_2eq attributed to secondary care in England per annum [Eastern Region Public Health Observatory, 2010].

This high-level estimation is intended only to provide context to the study. Its accuracy is undoubtedly compromised by a methodology which extrapolates data collected from a single renal service. Renal services provide care to differing numbers of patients, with differing social and medical demographics, and the proportions of these patients accessing the different components of the services (haemodialysis, peritoneal dialysis, inpatient care, outpatient care, transplantation) also varies greatly [Byrne, Steenkamp et al., 2010]. The extrapolation methodology accounts only for the absolute numbers of patients receiving renal replacement therapies under the care of the different renal services.

It has not been possible to account for the variation in the proportions of patients accessing the different components of the services. Although these data are available (at least for haemodialysis, peritoneal dialysis and transplantation, if not for patients not receiving renal replacement therapies) for each of the renal services across England, the difficulties of disaggregating the activity data collected from the Dorset Renal Service across its component parts (particularly within the different forms of RRT) prevent an approach in which the relative sizes of the components of the different services across England are afforded an accurate weighting in accordance with the contribution made by the corresponding component to the carbon footprint of the Dorset Renal Service.

Not all of the carbon footprint of NHS England can be attributed to clinical specialties. Indeed, a significant proportion of the carbon footprint of NHS England is not directly attributable to any of the clinical specialties. Examples of such areas might be the emissions arising from the Finance Departments or the Patient Liaison Services of hospitals incorporating renal services. Were carbon footprint assessments similar to this study to be undertaken for different specialties, it is likely that these emissions would again be considered to lie outside their boundaries. Therefore the carbon footprint of renal healthcare is greater than 0.93% of the carbon footprint of the clinical specialties, but the extent to which this is the case is not clear in the absence of data regarding the carbon footprints of the other specialties.

Carbon Emissions Per Unit of Healthcare Activity

But is renal medicine a carbon intensive specialty? Again, without results from other specialties for comparison, this is difficult to ascertain. The NHS England emissions of 21.28 million tonnes of CO_2eq per annum result from the provision of care to 51.4 million people (0.41 tonnes per patient per year) [Sustainable Development Commission, 2008]. Data regarding the proportion of the population of England accessing renal services are not available, and neither is similar data for the population covered by the Dorset Renal Service. However, data from the Renal Registry confirms that the proportion of the population of England receiving either haemodialysis or peritoneal dialysis is extremely small (0.04%) [Byrne, Steenkamp et al., 2010]. Yet, it is to be expected that the majority of the emissions arising from renal services result from the provision of these two forms of RRT, and indeed these two components of the Dorset Renal Service contribute 65.4% of its overall carbon footprint (Table 11). The provision of haemodialysis and peritoneal dialysis by the Dorset Renal Service to just 277 patients, from a population of 865,000, results in 1,965 tonnes of CO_2eq, equating to an emissions burden of 7.09 tonnes of CO_2eq per dialysis patient per year. Therefore, just as renal medicine is considered to be a ‘high cost, low volume’ specialty in financial terms, it seems likely that it is also a carbon intensive specialty when considered in terms of the numbers of patients treated with RRT.

This line of thinking is supported by the finding that a total of 824 of the 3006 tonnes of CO_2eq attributable to the Dorset Renal Service result from the provision of an estimated 5,110 inpatient bed days per year. This equates to a carbon burden of 161 kg CO_2eq per bed day (Table 13). Whilst this estimate was derived from aggregated activity data, and should therefore be considered to be indicative only, it is considerably higher than the only other published figure of this nature; the previously mentioned NHS SDU study [Eastern Region Public Health Observatory, 2010] estimated the GHG emissions associated with one bed day (within all clinical specialties) to be 80 kg CO_2eq through the application of four methodologies to data from the NHS England Carbon Footprinting report [Sustainable Development Commission, 2008]. The discrepancy appears to be largely due to the emissions arising from the procurement of pharmaceuticals and medical equipment, and is therefore perhaps explained in part by the provision of RRT to patients on the inpatient renal ward. Interestingly, although inpatient care is provided at a single site (DCH), the contribution of patient and visitor travel to the emissions associated with the provision of inpatient care is relatively small (4.4%).

The carbon emissions attributable to an outpatient appointment in the Dorset Renal Service have been calculated to be 22 kg CO_2eq (Table 12). This figure is based upon aggregated activity data and should also be considered to be indicative only. However, given the lack of carbon footprinting studies within healthcare, it is of note that this estimation, produced by a ‘bottom up’ approach, is comparable in magnitude to that of the only other published data, again from the ‘top down’ NHS SDU study [Eastern Region Public Health Observatory, 2010]. The NHS SDU study applied three different methodologies to data from the NHS England Carbon Footprinting report [Sustainable Development Commission, 2008] and reported estimations of 24, 38 and 78 kg CO_2eq per outpatient appointment. The figure reported here lies at the lower end of this range, perhaps reflecting the exclusion of pharmaceuticals prescribed from primary care.

Uncertainty in the Results

The nature of carbon footprinting methodology, in which every input has some degree of uncertainty associated with the assumptions and estimations relating to it, means that every carbon footprint has some degree of variation inherent within it. The higher the uncertainty, the lower the confidence with which the carbon footprint can be interpreted, and, in particular, used for comparison.

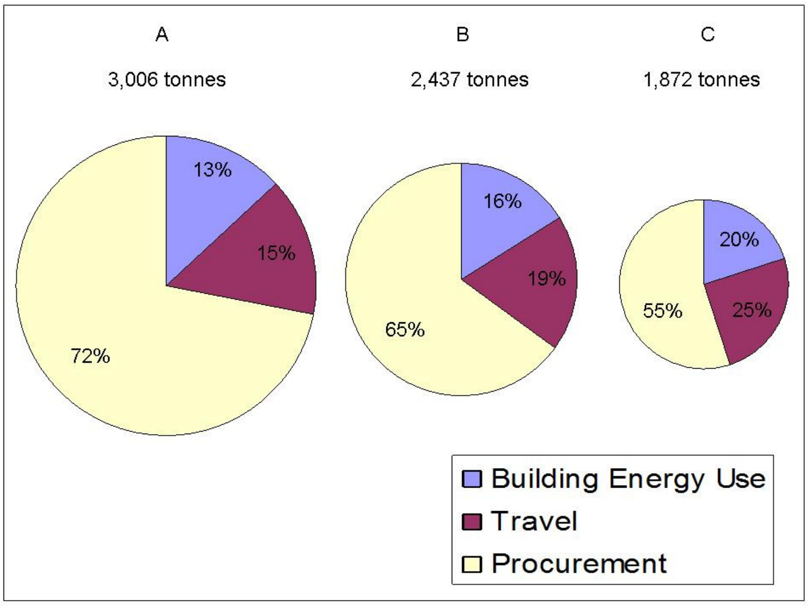
The process analysis and input-output approaches to carbon footprinting have different uncertainty profiles, and their use in isolation can present difficulties in interpreting these profiles. For example, the extent of any truncation error, which occurs within process analysis as a result of the exclusion of components of the service or product, can only be estimated using a top-down model. Conversely, the magnitude of aggregation uncertainty, which occurs in input-output assessments, can only be considered through comparison with process analysis data. These problems highlight a further benefit of the hybrid LCA approach. As this study is processed based, uncertainty exists around the possibility of truncation error.

Aside from uncertainty arising as a result of the methodology, uncertainty may derive from two further sources in any carbon footprint. Natural uncertainty results from changes within the product or service being assessed. As such, it may not easily be identified or quantified, can sometimes be ameliorated through adequate sampling, and is accounted for in the understanding that a carbon footprint is a representative rather than exact figure. Technical uncertainty results from flawed calculations (for example, as a result of incorrect assumptions or poor quality data) and may amenable to analysis. However, as the analysis is of only a single renal service, it is not possible to estimate variation at this level. Furthermore, as data have been collected from a single year, there is no scope to measure variation or error.

Further uncertainty arises from the use of supply chain emissions factors calculated from input-output economic tables based upon 2004 prices. Whilst the economic activity data have been deflated to maintain consistency with the emissions factors, emissions in more recent years may have changed because of subsequent changes in the structure and emissions intensity of the supply chain itself.

The measures taken to identify the most appropriate emissions factors for this study have been outlined previously. However, the considerable variation between emissions factors quoted by different sources for the medical equipment and pharmaceutical supply chains, and the extent to which these subsectors contribute to the carbon footprint, means that uncertainty is conveyed to the final results. Appendix 3 includes the complete results of the carbon footprint of the Dorset Renal Service derived using emissions factors for these subsectors from the National Statistics of Environmental Accounts, and also using values averaged between the emissions factors quoted by DEFRA and National Statistics of Environmental Accounts. Meanwhile Figure 5, below, illustrates the extent to which the use of the different factors influences not only the overall result but also the impact of the different sectors within the total.

Figure 5. The impact of the use of different emissions factors for the medical equipment and pharmaceutical subsectors upon the overall carbon footprint and the impact of the different sectors. (Emissions factors sourced from A. DEFRA, B. averaged figures, and C. National Statistics of Environmental Accounts).



Accurate carbon footprinting studies are vital to inform strategies to reduce the considerable environmental impact of healthcare. These results are presented to highlight the need for future research to refine the emissions factors relevant to the supply chains supporting the provision of healthcare. These emissions factors should ideally be tailored to use within the different specialties of medicine.

Recommendations

Recommendations to Reduce Emissions Associated with the Provision of Renal Healthcare

The results of this study should inform strategies to reduce the emissions arising from the delivery of renal healthcare. Measures to reduce emissions arising from the procurement of pharmaceuticals and medical equipment should be prioritised and these might take a number of forms. Firstly, the renal community should explore possibilities to reduce its consumption of pharmaceuticals, for example, through measures to improve compliance and reduce wastage. Similarly, opportunities to reduce the consumption of medical equipment should also be investigated, for example through the re-evaluation of the extent to which risk management defines infection control policies, such that the increasing trend towards single-use, disposable items might be reversed in favour of re-usable items (where these have been proven to be acceptably safe and to have a lower environmental impact). Secondly, the reduction of GHG emissions arising within the supply chains for these procurement subsectors should be incentivised. Research is therefore required to develop effective sustainability criteria for inclusion in the procurement contracts tendered by renal services. Such criteria should pay particular attention to the manufacturing stage, as the majority of pharmaceutical and medical equipment procurement emissions are believed to relate to building energy use during their manufacture [Sustainable Development Commission, 2008]. Finally, external influences, such as the Carbon Reduction Commitment, may also reduce manufacturing emissions.

In contrast to their lower financial costs, medical equipment and pharmaceuticals manufactured outside of Organisation for Economic Co-operation and Development (OECD) countries have higher embedded energy costs [Sustainable Development Commission, 2008]. Therefore, strategies to incentivise renal services to procure medical equipment and pharmaceuticals that were manufactured in OECD countries might be anticipated to reduce supply chain emissions, although such an approach would require the consideration of the wider ethical issues.

Recommendations to Improve the Use of Carbon Footprinting Studies within Healthcare

Further research, including carbon footprinting studies, is required to better understand the environmental impacts of healthcare technologies, treatments and pathways, such that these impacts can be considered during service reconfigurations. The experiences of the authors whilst undertaking this study prompt the following recommendations.

More specific emissions factors are required.

More specific emissions factors are required to facilitate accurate modelling of the effects of strategies designed to reduce the carbon footprint of renal medicine. This is particularly true for the procurement subsectors of pharmaceuticals and medical equipment, which contribute heavily to the carbon footprints of both NHS England and the Dorset Renal Service. Whilst there is likely to be considerable variation in the carbon intensities of the different types of pharmaceutical and medical equipment that exist within these subsectors, this is not reflected in the emissions factors currently available. For example, whilst the emissions factors used in this study for these subsectors are derived from a multi-region input-output model and therefore take some account of the emissions relating to the production of imported goods, future iterations of carbon footprint assessments of renal units should, if possible, identify where products are produced and will therefore require more specific carbon intensity values to reflect this. A practical approach may be to produce emissions factors for these subsectors specific to the different specialties of medicine.

Waste management represents another area in which the accuracy of carbon footprinting studies might be improved through the production of emissions factors that are more specific to healthcare. For example, the incineration of healthcare waste differs from the incineration of municipal waste. Not only is it likely to be undertaken at higher temperatures, but the materials being incinerated are likely to be different in nature to those of municipal waste. Such factors will influence the GHG emissions associated with the process, for example through their impact upon opportunities for energy recovery. It is unclear how well the emissions factors that are presently available for waste management represent the disposal techniques used in healthcare.

Improved accessibility to high quality primary data is required to increase the accuracy and ease of future carbon footprinting studies.

The accuracy of a carbon footprint is reliant upon the quality of the primary data available. This could be widely improved through simple measures, such as sub-metering of electricity consumption in renal units, regular auditing of waste disposal, and the use of more refined procurement data recording systems.

Standardisation of the methodologies used for carbon footprinting within healthcare is required.

Carbon footprinting methodologies are increasingly subject to standardisation. This report adheres to the principles and definitions defined within PAS2050 [British Standards, DEFRA, Carbon Trust, 2008]. However, it was considered pragmatic to depart from this methodology in particular areas, in order to more accurately reflect the carbon footprint of what a renal service is more widely understood to include. For example, the emissions attributable to patient and staff travel have been included in this study, although strict adherence to PAS2050 would dictate their exclusion. It would be preferable for future healthcare carbon footprinting studies to follow a unified methodology in order to ease their comparison and understanding. The advantages of adhering more rigidly to a proven and already widely used methodology such as PAS2050 (primarily simplicity) must be weighed against the advantages of the development of more healthcare-specific methodologies (arguably, that the definition of the service or treatment under study may be set to more accurately reflect the form that it is most widely perceived to take by the healthcare community).

Conclusions

Very few carbon footprinting studies have been published within the medical literature, despite a pressing need to develop an evidence base with which to support carbon reduction strategies within healthcare. This chapter has presented the first assessment of the carbon footprint of an individual specialty service to include both direct and indirect emissions, identifying the contributions of the three primary sectors (travel, building energy use and procurement). The GHG emissions of the provision of renal healthcare across England have been estimated from these results.

The methodology employed in this study can be translated to other renal services and might be used to inform similar studies in other specialties. The results of this study might be used to inform carbon reduction strategies in renal services.

Chapter 5.

The Greenhouse Gas Emissions associated with the Provision of Home and In-centre Maintenance Haemodialysis in the United Kingdom.

Introduction

The lack of evidence to support the implementation of carbon reduction strategies within the provision of renal healthcare was highlighted in Chapters 2 and 3. Chapter 4 has begun to address this deficit by reporting the carbon footprint of an individual renal service, in which the provision of healthcare to patients requiring dialysis was identified as a substantial contributor to the overall GHG emissions. An opportunity for clinical transformation might therefore exist within the delivery of haemodialysis to patients with ESRD. Within the United Kingdom, haemodialysis forms the cornerstone of most RRT programmes and the prevalence of haemodialysis patients is increasing year on year [Byrne, Steenkamp et al., 2010]. Haemodialysis is provided either in dialysis facilities ('in-centre haemodialysis', ICHD) or in patients' own homes ('home haemodialysis', HHD). The uptake of HHD varies dramatically between and within countries, and has declined considerably in many regions [MacGregor et al., 2006]. This is the case in the United Kingdom, where, on the 31st December 2008, 43% of prevalent patients on RRT programmes received ICHD whilst just 1.1% undertook HHD [Byrne, Steenkamp et al., 2010]. The decline in the numbers of patients undertaking HHD in the United Kingdom has been not only a relative one (the result of increases in the numbers of patients receiving the alternative forms of RRT, such as transplantation, ICHD and peritoneal dialysis) but also an absolute one (with reductions in the actual numbers of patients receiving HHD). Significant expansion of existing HHD programmes is likely to be possible in many countries, including the United Kingdom, and technological advances in haemodialysis machines should help to facilitate this.

The National Institute for Health and Clinical Excellence (NICE) has advocated that all suitable patients should be offered the choice between HHD and ICHD [National Institute for Health and Clinical Excellence, 2002], and has suggested that, based upon assumptions regarding patient's likely preferences, renal services should be able to provide HHD to 15% of patients requiring dialysis. Furthermore, it is also likely that the rising numbers of patients dialysing at home will, for clinical reasons,[†] be encouraged to dialyse more frequently (consuming more single-use equipment and producing more plastic and packaging waste) and for longer (requiring more electricity and water). The point at which the increase in GHG emissions that result from the more frequent and longer dialysis treatments that are likely to be undertaken by HHD patients outweigh the reduction in the travel emissions of these patients, compared to those receiving ICHD, is not clear.

In anticipation of the changing face of haemodialysis programmes in the United Kingdom, this chapter reports the undertaking of a study designed to improve our understanding of the environmental impacts of the differing modalities and regimens of haemodialysis treatments.

Aims

The primary aim of this study is to determine the carbon footprints of the differing modalities and treatment regimes commonly used to deliver maintenance haemodialysis, in order to inform decision-making around the provision of haemodialysis services. The secondary aim is to calculate the contributions of the constituent components of haemodialysis treatments to these carbon footprints, in order to inform carbon reduction strategies at the level of individual treatments.

[†] Relatively large oscillations occur in a patient's weight (which represents fluid retention between dialysis sessions) and blood metabolite concentrations when dialysis treatments are provided three times a week, and these are known to be a major cause of morbidity [Ing et al., 2006]. More frequent dialysis treatments lessen the extent of these oscillations and, in turn, confer a number of benefits [Lindsay, 2008]. Not only are the dialysis treatments themselves better tolerated, but other indicators of morbidity (including anaemia, blood pressure control, nutritional status) are also improved, and patients typically require fewer hospitalisations and enjoy a higher quality of life. Meanwhile, similar benefits result from the improved fluid balance achieved through increases in the duration of dialysis treatment times (for example, nocturnal dialysis) [Twardowski, 2007].

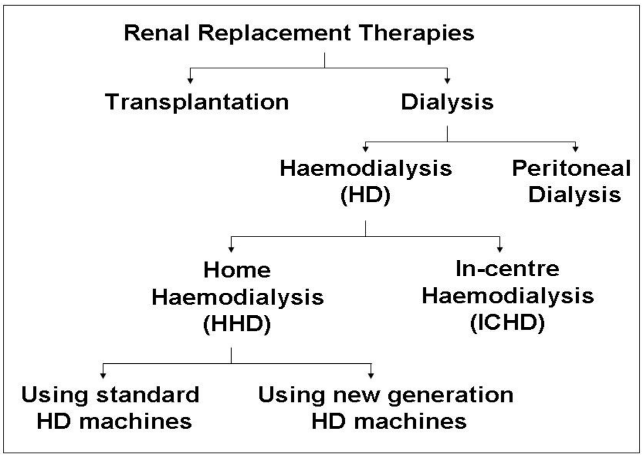
Methodology

Haemodialysis Services

ESRD is defined as irreversible and total (or near-total, see Appendix 1) loss of kidney function and may result from progressive disease of the kidneys or, less commonly, from an acute kidney injury. Patients with ESRD are likely to experience clinical symptoms as a result of the retention of waste products and toxins, and also as a result of anaemia, hypertension, oedema and acidosis. When a patient's renal function declines to the point at which their kidneys are considered to be unable to support life in the longer term, consideration must be given to commencing RRT.

RRT programmes typically include a number of different treatment modalities and patients with ESRD may switch between these over time (Figure 6). Kidney transplantation is the treatment of choice for many patients. However, not all patients are suitable for transplantation. This, in conjunction with other factors such as the constraints on donor organ availability, results in around half of all those patients receiving RRT in the United Kingdom undertaking dialysis. This is most commonly haemodialysis (44.1% of prevalent RRT patients), with smaller numbers undertaking peritoneal dialysis (9% of prevalent RRT patients) [Byrne, Steenkamp et al., 2010]. In contrast to renal transplantation, both haemodialysis and peritoneal dialysis replace only the primary functions of the kidneys – namely the maintenance of fluid balance and the removal of the waste products of metabolism. Furthermore, these treatments undertake these functions far less effectively than healthy kidneys. The point at which patients with ESRD will benefit from RRT remains an area of uncertainty in clinical practice, and the introduction of RRT should be considered on an individual patient basis.

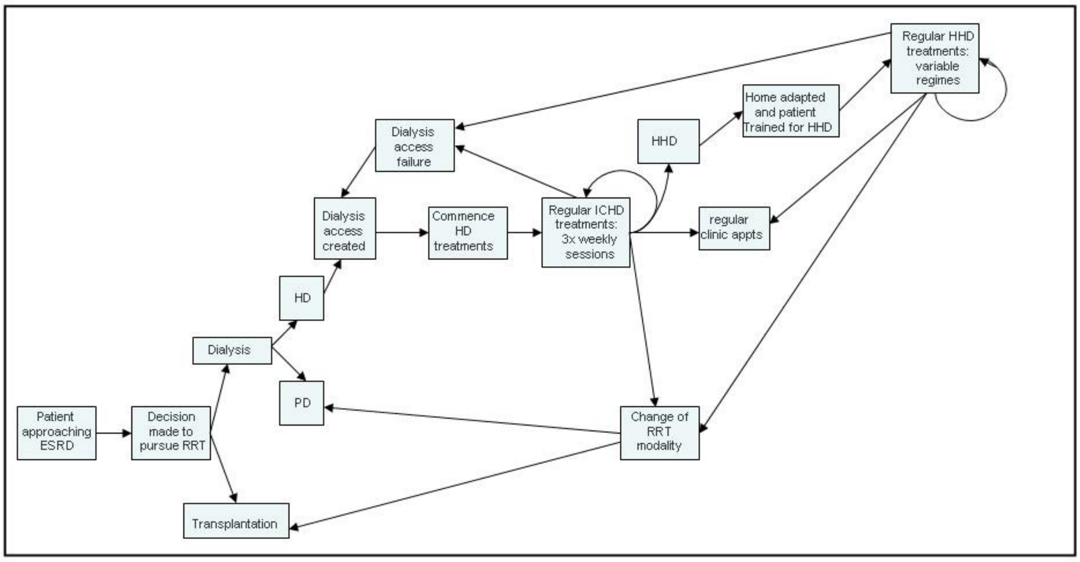
Figure 6. The different modalities of RRT.



As was previously mentioned, haemodialysis may be provided in centre (ICHD) or at home (HHD). At present, the haemodialysis machines used in both ICHD and HHD are broadly similar and are referred to in this study as 'standard'haemodialysis machines. However, new technology has resulted in the recent availability of dialysis machines with particular advantages for HHD patients.

The pathway followed by the majority of patients commencing haemodialysis is shown in Figure 7. Dialysis 'access' (either a fistula or central venous catheter) must be created prior to the first treatment, and is required to connect the patient to the haemodialysis machine and enable regular treatments. Patients typically commence ICHD, and those wishing to pursue HHD will learn to do so at the ICHD facility.

Figure 7: A process map of the provision of repeated treatments of ICHD and HHD.



Patients may switch between the different forms of RRT. Patients established on either haemodialysis or peritoneal dialysis might, for clinical reasons, switch to the alternative form of dialysis or they may receive a kidney transplant. Likewise, transplanted patients may later require haemodialysis or peritoneal dialysis. It should also be remembered that patients on RRT may die.

Process Mapping a Single Treatment Session of Haemodialysis to an Individual Patient

Within the haemodialysis pathway, it is anticipated that the majority of the emissions will result from the repeated treatment sessions of either ICHD or HHD. It is therefore essential to appreciate the processes and products involved in the provision of a single haemodialysis treatment to an individual patient, and to note the similarities and differences that exist between the provision of HHD and ICHD.

Travel

For patients receiving ICHD, a session of haemodialysis treatment begins with the patient travelling to the site at which the dialysis treatment is provided and ends with their travel home.

This travel may be undertaken privately or may be provided by the hospital providing their overall care. Patients undertaking HHD do not travel to undertake dialysis.

The provision of ICHD also routinely requires that staff members travel to the haemodialysis facility, including nursing staff, renal technicians, administration and domestic staff. Nursing staff and renal technicians will undertake occasional visits to the homes of patients undertaking HHD.

The Dialysis Environment

The environments in which patients undergo haemodialysis are therefore very different. Facilities for ICHD vary in size, but may typically have between 8 and 30 'stations' at which individual patients will simultaneously receive haemodialysis. The infrastructure used, and building energy use required, to provide the necessary space, lighting, heating, ventilation and air conditioning will vary between facilities (and, of course, over time), but a degree of standardisation might be expected to result from the guidance that exists in this regard [Renal Association, 2009; NHS Estates, 2004]. In contrast, greater variation in these parameters is likely to be evident in the dialysis environments of the patients undertaking HHD.

Healthcare professionals are present in dialysis facilities at all times, and a single nurse will typically be responsible for the care of either three or four patients undergoing ICHD at any one time. Although HHD patients are usually encouraged not to dialyse when alone, they are often trained to provide all aspects of their care by themselves.

Water

Large quantities of high grade water are required to provide haemodialysis using standard machines. Although variations will exist between dialysis facilities, a typical approach to water purification and storage might be as follows. Mains water is first pressurised by a pump before passing through a pre-treatment system (usually including carbon filtration and water softening treatments) and subsequently a reverse osmosis system. Although reverse osmosis systems vary in efficiency, significant volumes of good quality 'reject water' are lost-to-drain in the vast majority of United Kingdom facilities and homes. Meanwhile, the majority of the purified water is delivered by direct feed to the haemodialysis machines, where it is used to produce dialysate, whilst the remainder is stored in a tank and maintained at 60 °C prior to its use for periodic 'loop disinfections'. During these 'loop disinfections', discussed below, this stored water is heated from 60 to 90 °C and a volume is flushed through the pipe work supplying the haemodialysis machines. Electrical energy is therefore required to power the pumps and heaters used in these processes.

For those patients undertaking HHD using standard machines, a smaller reverse osmosis system is used to purify water on demand. Loop disinfections, and therefore water storage systems, are not required.

Acid

Dialysate production also requires a supply of acid (a concentrated solution of salts – including sodium, potassium, calcium, magnesium, chloride and dextrose - which is mixed in proportion with purified water to form dialysate). This acid is commonly provided in six litre plastic canisters and proportioned in the individual dialysis machines. However, some facilities providing ICHD use a central acid delivery system, in which the acid required to make the dialysate is delivered into a central tank within the dialysis facility and then distributed to the dialysis machines during treatments via a piped loop system with outlets at each dialysis station. This system is present in approximately half of United Kingdom dialysis facilities and negates the need for the acid to be provided in individual canisters.

Bicarbonate

To complete the production of the dialysate, a buffer is also added to the solution. Bicarbonate is now preferred to acetate for this role. The bicarbonate is supplied in a separate plastic container.

Priming and Disinfection Regimes

Prior to every treatment, all standard haemodialysis machines must be primed with purified water. Regular disinfections are also required. The timing and nature of these disinfections varies across haemodialysis facilities. For an ICHD facility, a typical regime might be as follows: a heat disinfection is undertaken prior to the first patient of the day; a combined heat and citric acid disinfection is undertaken prior to the second patient of the day; further heat disinfections are undertaken prior to, and after, the final patient of the day; once a week, a chemical (cold bleach) disinfection is undertaken after the final patient of the day.

Similarly, the disinfection regimes undertaken by patients using standard machines to provide HHD will vary, but a typical regime will involve a heat disinfection prior to a treatment session, a combined heat and citric acid disinfection after a treatment session, and a chemical (cold bleach) disinfection once a week.

Connecting to the Haemodialysis Machine

The patient is connected to the dialysis machine ('putting the patient on'). This is most commonly achieved by 'needling the fistula' - inserting a needle into a surgically created anastamosis between a vein and an artery, usually in the patient's arm - and connecting the needle to the blood lines that run to and from the haemodialysis machine. Alternatively, the patient may have a central venous catheter in situ, to which the blood lines can be connected directly. The method used to connect the patient to the machine will influence both the items of medical equipment that are used (most of which are disposable single-use products) and the plastic and packaging waste that is generated. Whilst most patients undertaking HHD will learn to perform this procedure themselves, it will be performed by members of the dialysis nursing staff for the majority of patients receiving ICHD.

The Dialysis Treatment

During haemodialysis, blood is removed from the patient, travels down a blood line and is pumped through a dialyser. Inside the dialyser, waste products in the blood diffuse across a membrane into the 'dialysate' fluid, a blend of treated water and chemicals. The blood is then returned to the patient through a second blood line. Blood continues to cycle between the patient and the dialysis machine throughout the duration of the treatment session.

Dialysis relies upon the principle of diffusion of solutes across a semi-permeable membrane down a concentration gradient. In this way, solutes may move out of the blood, for example the removal of urea or creatinine, or into the blood, for example the replenishment of serum bicarbonate. Modern dialysis membranes ('dialysers') are commonly synthetic and, in the United Kingdom at least, are single-use (a topic discussed in Chapter 2). As such, dialysers represent another example of the many consumable products involved in the provision of haemodialysis, each of which is associated with plastic and packaging waste as well.

The principle of ultra-filtration, in which the convective flow of water and dissolved solutes results from a pressure gradient caused by hydrostatic and osmotic forces, is utilised to drive water through the dialyser and remove it from the patient as necessary. This fluid is lost-to-drain.

At its simplest, therefore, a standard dialysis machine consists of a blood pump, a system to deliver 'dialysate' fluid (a blend of treated mains water and chemicals), a heater, and safety monitors. A dialysis facility, or home environment, supporting the use of standard dialysis machines will also require a water purification system.

The end of the Treatment

At the end of the session, the patient is disconnected from the dialysis machine. The blood lines, dialyser and, in the case of patients dialysing through fistulas, the needles, are disposed of in the clinical waste stream. Those patients receiving, and those staff providing, ICHD must, of course, then travel home.

The standard haemodialysis machines are rinsed after every use. In addition to the heat, citric acid and chemical disinfections detailed previously, a further disinfection process is undertaken in ICHD facilities. This 'loop' or 'integrated' disinfection is required to disinfect the pipe work running between the water purification system and the water outlets to each haemodialysis station. The frequency with which this disinfection process is undertaken varies between daily and weekly across ICHD facilities.

New Technologies

Dialysis technologies evolve continuously and recent advances have produced machines with clear advantages for patients undertaking HHD. One such example is the NxStage System One^{TM} dialysis machine [Clark & Turk, 2004]. The availability of this device is considered to be playing a major role in the increasing uptake of HHD in the US. At the end of 2007, there were 2,196 patients in the US using NxStage equipment for short daily dialysis [Blagg, 2010]. This figure has now risen beyond 3,000 patients (information provided by Kimal plc, United Kingdom distributor for NxStage, by verbal communication, 15th May 2010), although the numbers of patients using NxStage equipment in the United Kingdom remain very small. The principal benefit of the machine is that it is transportable.

The NxStage System One^{TM} machine is the smallest haemodialysis system approved by the US Food and Drug Administration agency for home use and is considerably smaller than standard haemodialysis machines. The dialyser and blood lines are provided together, in a pre-packaged plastic cassette. The NxStage System One^{TM} machine is designed to be used with the NxStage PureFlow^{TM} SL device, which prepares up to 60 litres of dialysate (a volume sufficient for between two and three treatments, and which can be stored for up to 72 hours) in a 'SAK' (a plastic container) from mains water within a six hour running time, using a pre-packaged disposable filtering system (a 'PAK') which must be replaced every 12 weeks. Although it removes the need for a reverse osmosis water purification system, and therefore also for plumbing modifications, the NxStage PureFlow^{TM} SL device itself is not portable. Therefore, when patients travel with the NxStage System One^{TM} machine, they instead derive the dialysate from pre-made five litre bags, of which between four and six are required for each short daily dialysis treatment.

There are therefore two treatment scenarios for patients using the NxStage equipment. When dialysing at home, they will pre-prepare 60 litres of dialysate from mains water using the NxStage PureFlow^{TM} SL device after every second or third treatment. The NxStage PureFlow^{TM} SL device will draw electricity from the National Grid during all periods of dialysate production and storage. The patient will connect to, and disconnect from, the NxStage System One^{TM}

machine in the manner described for a standard haemodialysis machine. During their treatment, both the NxStage PureFlow™ SL device and the NxStage System One™ machine will be drawing mains electricity. After each treatment they will dispose of the waste in clinical and domestic waste streams. In the second treatment scenario, when the patient is travelling away from home, the NxStage PureFlow™ SL device will not be used. The procedure will be as described, with the exception that the dialysate will be hung above the NxStage System One™ machine in four to six pre-packaged fluid bags.

Consumables

The increased availability of haemodialysis has been dependent upon the use of pre-packaged, single-use, disposable items of medical equipment. These 'consumable goods' enter the process at different stages and subsequently produce waste. The consumables used during the provision of a treatment of ICHD include the blood lines, the dialyser, syringes, needles, acid canisters, bicarbonate cartridges or bags, sterile gloves, aprons, face masks and dressing towels.

As has been mentioned previously, both longer treatment times and increased dialysate flow rates increase the volume of dialysate required. When the acid for dialysate is supplied in canisters, these changes can lead to the need for a second canister. The amount, and nature, of the remainder of the consumables involved in a single treatment session using a standard haemodialysis machine are likely to be similar regardless of either the treatment duration or whether it is undertaken as HHD or ICHD. However, these consumables are very different to those required for a single treatment using Mobile HHD equipment.

Treatment Regimes: the Frequency and Duration of Haemodialysis Sessions

Both the duration and frequency of haemodialysis treatment sessions can be varied and represent important considerations when ensuring that patients receive a satisfactory 'dose' of dialysis. The majority of patients receiving ICHD are prescribed thrice weekly sessions, each lasting 240 minutes. This scenario is considered to provide the optimal balance between the constraints imposed by limitations in the resources available and the clinical requirements of the patients.

However, the situation is very different for patients undertaking HHD and who are in a position to determine for themselves, with guidance from their physician, how frequently and for how long to undergo dialysis. HHD patients are increasingly encouraged to dialyse more frequently than three times a week, and sometimes for longer (for example, nocturnal dialysis).

The situation is different again for patients using NxStage machines, in which the slower dialysate flow rates necessitate longer treatment times (with six hours of dialysis providing a dose approximately equivalent to four hours of dialysis using a standard haemodialysis machine). However, this is offset by the improved convenience of the system, and patients will typically make up these hours by dialysing more frequently rather than for longer periods.

Given these variations in treatment durations and frequencies, this study assesses a selection of the more common regimes followed by patients undertaking treatments from the different modalities of haemodialysis (see Table 14).

Table 14: The dialysis regimes assessed within this study.

Modality	Machine Type	Regime	
		Frequency of Treatments	Duration of Treatments
ICHD	Standard	Three days a week	4 hours
HHD	Standard	Three days a week	4 hours
HHD	Standard	Four days a week	4.5 hours
HHD	Standard	Five days a week	4 hours
HHD	Standard	Six days a week	2 hours [a]
HHD	Standard	Six nights a week	7 hours [c]
HHD	Standard	Three nights a week	7 hours [c]
HHD	Mobile, NxStage	Five and a half days a week [b]	3 hours [a]
HHD	Mobile, NxStage	Six nights a week	7 hours [c]

[a] Three hour treatments using a NxStage System One^{TM} machine provide a dialysis dose approximately equivalent to that provided by a 2 hour treatment using a standard haemodialysis machine.

[b] This figure is derived from the fact that treatment regimes using NxStage System One^{TM} machines most commonly have a treatment frequency of 5 or 6 days a week.

[c] Patients undertaking nocturnal regimes will typically dialyse for between 6 and 8 hours.

Previous Studies to Assess the Environmental Impact of Haemodialysis

Whilst consideration has been given to both the environmental impact of the use of consumables within haemodialysis and the financial implications of providing HHD and ICHD [Upadhyay et al., 2007; Hoenich et al., 2005; Baboolal et al., 2008], only one study has attempted to determine the respective environmental impacts of HHD and ICHD [James, 2007]. Methodological difficulties in analysing the absolute carbon footprints of these two modalities prompted the adoption of a comparative approach in which quantification of the differences in their environmental impacts was attempted. In this study, data relating to transport and water use (including both its supply and subsequent treatment) were acquired and HHD was found to produce less emissions (0.207 tonnes of CO_2) than ICHD (1.404 tonnes of CO_2) per patient per year. This discrepancy was predominantly attributed to the absence of emissions related to patient travel in HHD. These findings should be interpreted with caution as several potentially significant sources of emissions were excluded. These exclusions understandably included areas of commonality between HHD and ICHD, such as the use of similar haemodialysis machines, and also the highly variable aspects of building energy use such as heating and lighting. However, in the light of the findings of the study reported in Chapter 4, perhaps the most important exclusion was that of the emissions arising within the supply chains and attributable to the manufacture of the consumable products (predominantly clinical supplies) required for the provision of haemodialysis. The emissions associated with the disposal of these products were also not determined. Furthermore, no consideration was given to the variations in treatment regimes that exist between HHD and ICHD patients. The data were collected from small numbers of patients, and, importantly, the study pre-dated the emergence of the newer dialysis technologies.

A single session of ICHD might be anticipated to produce considerably more GHG emissions than a single outpatient appointment. The aforementioned study assumes that patients undergo dialysis thrice weekly for 52 weeks a year, and reports that these 156 sessions result in 1,404 kg CO_2 emissions – or 9 kg CO_2 emissions per session [James, 2007]. It must be assumed that these figures describe only the CO_2, rather than all GHG, emissions. However, this figure is still considerably lower than the indicative carbon burden attributed to a single outpatient appointment by both the study reported in Chapter 4 (22 kg CO_2eq) and the work of others (50 kg CO_2eq) [Eastern Region Public Health Observatory, 2010], a finding which probably results, at least in part, from the exclusions detailed above.

Emissions Terminology

The Kyoto Protocol recognises six GHGs in its targets [United Nations Framework Convention on Climate Change, 2008]. CO_2 is released from both natural events (such as volcanism) and the burning of fossil fuels by man. As a result of the latter, CO_2 is, by some margin, the most prevalent anthropogenic GHG within the atmosphere aside from water vapour. Emissions of GHGs may be quantified in terms of their global warming potential - the global warming potential of 1 kg of the gas in question being equivalent to the amount of a reference gas that would produce an effect of similar magnitude over a defined time period. The IPCC recognises three time periods, of which the most commonly used is 100 years. CO_2 is the gas most commonly used as the reference gas. Therefore the emissions of other gases are frequently expressed in the units of CO_2eq. Within the US Health Care Sector, approximately 80% of the total global warming potential has been attributed to CO_2 emissions [Chung & Meltzer, 2009]. Similarly, over 85% of the NHS England GHG emissions were CO_2 emissions [Sustainable Development Commission, 2008]. Furthermore, this remained uniform between sectors and subsectors, with minor exceptions being food procurement and waste, which have increased

GHG emissions due to production and degradation of organic material. This figure of 85% is also comparable to the CO_2 proportion from all United Kingdom emissions. However, the remaining five GHGs recognised by the Kyoto Protocol have higher global warming potential than CO_2 and therefore contribute significantly to climate change, even if emitted in small volumes. The study includes the two of these GHGs (methane (CH_4) and nitrous oxide (N_2O)) anticipated to be of the greatest relevance to healthcare-associated emissions.

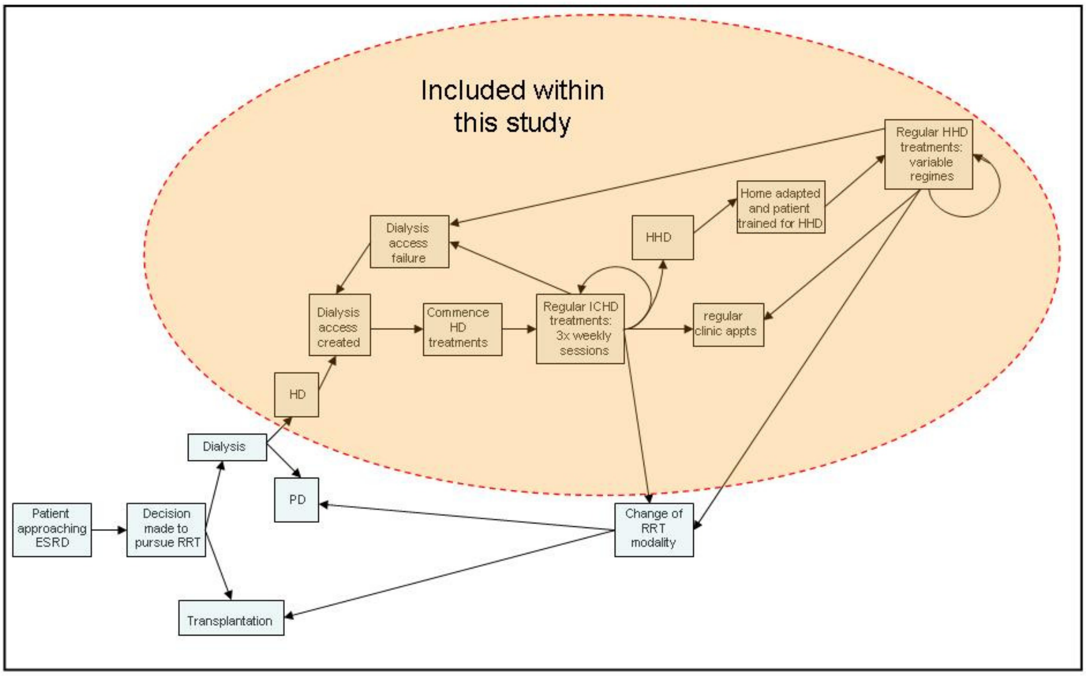
Unit of Measurement

Total emissions, including CO_2 and non-CO_2 (CH_4 and N_2O) GHGs, have been calculated across the components of the different haemodialysis modalities and are reported in tonnes of CO_2eq per year.

Boundary Setting

The sources of emissions included in this study were identified after consideration of, firstly, the individual components of the process of providing repeated treatment sessions of haemodialysis (outlined previously, and including dialysis access surgery) and, secondly, the impact of these components in terms of building energy use, travel and transport, and procurement (including waste). The sources of emissions included in this study are shown in Figure 8.

Figure 8: Schematic representation of the boundaries of this study.



Building Energy Use

The building energy use, and associated emissions, directly attributable to the provision of haemodialysis has been included in this study. This energy use includes, but is not limited to, the electricity required to power the haemodialysis machines, water purification systems, and water storage systems. Emissions arising from the building energy use related to the heating, cooling, and lighting of the environment in which the haemodialysis treatments are provided have not been included (as this energy use is likely to vary at different sites and points in time).

Travel and Transport

Emissions arising from staff and patient travel are included within the boundary.

Staff Travel

The emissions arising from the travel of all staff required to provide a treatment of dialysis is included. This includes dialysis nursing staff, administrative staff, technicians and domestic staff. Where staff may contribute to the provision of more than one haemodialysis treatment, the emissions arising from their travel are allocated proportionately.

Although PAS2050 [British Standards, DEFRA & Carbon Trust, 2008] demands that the system boundary of the service should exclude GHG emissions associated with the travel of employees to and from their normal place of work, this report includes the commuting travel of all staff (as well as their business travel) in order to maintain consistency with the NHS England Carbon Footprinting Study [Sustainable Development Commission, 2008].

Patient Travel

PAS2050 demands that the system boundary of the service should exclude GHG emissions associated with the travel of 'consumers' (in this case, patients) to and from the point of service use (the dialysis facility and home environment for ICHD and HHD respectively) [British Standards, DEFRA & Carbon Trust, 2008]. However, the travel of patients to receive ICHD was considered to be an integral component of the delivery of an ICHD programme, and also to represent a significant source of emissions. Therefore, all travel undertaken by patients to attend haemodialysis treatments has been included.

Transport

The transport of the consumable goods required to provide haemodialysis has been included in this study.

Procurement

As the footprint includes both direct and indirect emissions, those emissions relating to the procurement of the consumable products required to provide a haemodialysis treatment have been included; namely, the procurement of medical equipment, paper and office supplies, laundry services, construction, water, sanitation products (including chemicals for the external decontamination of haemodialysis machines), and the collection, treatment and disposal of waste.

Specific Boundaries Set Within Procurement

Medical Equipment

The items of medical equipment required to provide single treatments of ICHD and HHD are detailed in full in Appendices 4 and 5.

Waste

The disposal of all forms of waste produced during the provision of haemodialysis is included. The domestic waste that is recycled requires further comment as, since the recycling process is not undertaken within the renal services providing the haemodialysis, the carbon recovered is arguably realised outside of the boundary of this carbon footprint study. However, in order to maintain consistency in the approach to waste management, the DEFRA emissions factors for recycling were applied to this waste (in preference to considering the disposal of this waste to have no impact upon the overall carbon footprints of the different haemodialysis regimes).

Construction

A dedicated area within the appropriate built environment is integral to the provision of both ICHD and HHD (although this is arguably less true for the Mobile HHD technologies), and the emissions arising from the construction work required to both install and maintain such an area have therefore been included within this report. It should be noted that PAS2050 excludes all capital goods, including buildings, and it might therefore be reasonable to assume that emissions associated with the installation and maintenance of such capital goods should also be excluded [British Standards, DEFRA & Carbon Trust, 2008]. However, the inclusion of these emissions sources is considered necessary to facilitate an accurate comparison of the ICHD and HHD modalities.

Universal Exclusions

The following sources of emissions were considered to lie outside of the boundary of this study; the production of machinery used repeatedly (including haemodialysis machines and information technology hardware); pharmaceuticals; visitor travel; food; scientific research into renal medicine; staff and patient training; water use other than that used in haemodialysis; heating and lighting; business services; and immaterial emissions sources (those anticipated to be less than 1% of total footprint). The exclusion of particular emissions sources merits further comment.

Machinery

The emissions attributable to the production of haemodialysis machines have been excluded from this study. This is in keeping with the recommendations of PAS2050 [British Standards, DEFRA & Carbon Trust, 2008]. It is acknowledged that the carbon footprints determined in this study are accordingly smaller than would be the case had these emissions been included. However, although it is commonplace for an individual haemodialysis machine to be used to provide haemodialysis to multiple in-centre patients, but to only one HHD patient, it is considered unlikely that the exclusion of these emissions will unduly bias the results in favour of the provision of HHD using standard haemodialysis machines. The explanation for this is as follows. Current United Kingdom guidelines suggest that haemodialysis machines are replaced at between 25,000 and 40,000 hours of use or after a period of 10 years of use (whichever comes sooner) [Renal Association, 2009]. A machine being used by a HHD patient for four hours thrice weekly would accrue 624 hours of use a year, and would therefore have to be retired from service after 10 years (having performed only 6,240 hours of dialysis – 33,760 hours less than the machine might be safely used for). Meanwhile, a machine being used to provide ICHD might be used for up to 12 hours a day (providing three patients with four hour treatments) for six days a week, thereby accruing 3,744 hours of dialysis a year and requiring retirement from service at just under 11 years. In order to maximise the efficient use of a fleet of dialysis machines, the dialysis technician of a renal service will therefore commonly rotate the machines such that each machine spends the majority of its working life providing ICHD and smaller periods of time providing HHD. However, it must also be acknowledged that the emissions attributable to the production of standard haemodialysis machines and NxStage equipment may differ and the results of this study do not account for this.

The emissions related to the consumable items of medical equipment (those with an anticipated life-span of less than one year) used within haemodialysis machines are included.

Pharmaceuticals

Polypharmacy is common amongst patients with renal disease. This is reflected in the finding, of the study reported in Chapter 2, that 35% of the emissions attributable to a renal service result from the procurement of pharmaceuticals, in comparison to their contribution of 21% of the overall emissions of NHS England [Sustainable Development Commission, 2008]. However, emissions arising from the procurement of pharmaceuticals have been excluded from this study for two reasons. Firstly, most renal services would allocate the provision of pharmaceuticals and haemodialysis to two discrete and separate financial budgets. Secondly, although there is evidence to suggest that switching patients to the more intensive haemodialysis treatment regimes may facilitate reductions in the overall pharmaceutical burdens they experience [McGregor et al., 2001; Kuhlmann, 2010], accurate data regarding the extent to which this occurs across the different modalities and regimes is not available.

It should be noted that the acid and alkali fluids used in haemodialysis are not generally considered to be pharmaceuticals (as is evidenced by the fact that they are procured by Supplies Departments rather than Pharmacy Departments) as they do not enter the human body. However, as these fluids are produced to pharmaceutical grade quality, the emissions factors for pharmaceuticals have been used in calculations relating to the emissions attributable to these fluids (with the emissions attributable to the canisters containing them being calculated separately).

Blood Tests

It is standard practice for patients receiving haemodialysis to undergo monthly blood tests. The results inform the prescription of both future haemodialysis treatments and medications. The previously reported study, in which the carbon footprint of a renal service was determined, has included the emissions attributable to these blood tests. In the absence of an appropriate emissions factor, an individual blood test was assigned a nominal carbon cost of 0.05 kg CO_2eq. The application of a similar value in the context of this study identified that the contribution of the emissions attributable to blood tests to the carbon footprint of the provision of haemodialysis was less than 1%, and this emissions source has therefore been excluded.

Staff and Patient Training

This study reports the carbon footprint of the provision of maintenance haemodialysis to patients established on the respective modalities and regimes. The initial few months of haemodialysis treatment might be anticipated to be more resource intensive, particularly for patients undertaking HHD. This might explain the finding that the financial costs of HHD are slightly higher during the first few months of treatment [Baboolal et al., 2008]. However, the study includes only those components of a service required to provide haemodialysis to patients already established on the treatment. Aspects such as, for example, patient training, are therefore not included.

Accounting Period

This study calculates the total emissions arising from the provision of haemodialysis using different modalities over one year. Data has been collected from the most recent sources available (2009/2010 for the majority of data).

Data Sources and Assumptions

In order that this report is truly meaningful, and to facilitate replication, the assumptions made in the methodology and data collection are outlined here.

General Assumptions

Most renal services in the United Kingdom currently provide ICHD to the significant majority of their patients receiving haemodialysis, with a far smaller proportion of patients undertaking HHD. Whilst the numbers of HHD patients might be anticipated to increase over the coming years, it is inconceivable that the facilities required to provide ICHD will become redundant. In most services, these facilities currently contribute to the care of HHD. For example, the administration work to coordinate the care of HHD patients is commonly undertaken by the administration team based in the ICHD facility. For the purposes of this study, it has been assumed that these services will continue to be provided in this way.

It has been assumed that an in-centre dialysis facility consists of 15 stations and runs three shifts per day to full capacity, thereby providing ICHD to 45 patients each day.

It has been assumed that a patient undergoing ICHD receives 3 sessions per week and, therefore, 156 sessions per year.

It has been assumed that patients receive haemodialysis rather than haemodiafiltration. Although this latter form of treatment, which utilises higher hydrostatic pressures across the semi-permeable membrane to achieve further solute clearance by convection, consumes approximately 20% more water, the results of the study reported in Chapter 4 indicated that water consumption was unlikely to make a significant contribution to the overall carbon footprint of the provision of haemodialysis.

It has been assumed that the process of priming a standard machine for HHD will take 20 minutes. It has been assumed that the priming time increases to 40 minutes for a standard machine being used to provide ICHD, on the basis that all machines will perform a self test at start up lasting approximately 15 minutes. During this time, blood lines can be primed and fistulas needled – however it is common for the treatment to commence up to one hour later (as this sequence is designed to ensure that the machine is ready for use as soon as the patient arrives).

With the exceptions of the assumptions made regarding the successful creation of dialysis access that are detailed later, it has been assumed that no unforeseen clinical or technological complications arise during the provision of haemodialysis.

Travel

Patient Travel to ICHD

Data regarding patient travel to attend for ICHD were derived from the data collated for the Patient Transport Survey Report undertaken as part of the National Kidney Care Audit [Health and Social Care Information Centre, 2010]. These data were collected from all patients receiving haemodialysis in participating units on the 15^{th} and 16^{th} of October 2008. These dates were chosen because they captured weekday journeys, avoided school or national holidays, and were considered to be representative of ‘average days’. Two consecutive days were chosen to ensure that all patients receiving ICHD on three or more days per week (and many of the small number of patients who receive ICHD only twice per week) in participating units were captured once. At the time of the survey there were 247 separate locations for ICHD in England, Wales and Northern Ireland. Of these, 216 adult ICHD facilities provided sufficient data to be included in the survey and there was an overall patient response rate of 67.2%.

The following items of data were accessed for 11,285 adult patients.

1. **the modes of transport used by each patient for their outward and return journeys**; namely, hospital transport vehicle, ambulance services vehicle, car, public transport, taxi, active travel (walking or cycling), or other modalities. For the purposes of this study, those patients reporting to have travelled by ‘public transport’ were assumed to have travelled by bus. Those

patients reporting to have travelled by 'other' modalities were excluded from the data used in this report. Where data regarding the modality of travel were provided for only the outward or return journey, the modality was assumed to be the same for both journeys. Where data regarding the modality of travel were not provided for either journey, the patient's data were not included.

2. **the distance travelled by each patient**. For 87.9 percent of the 11,285 patients, this was calculated 'as the crow flies' from the patient's home postcode to their dialysis facility, and, as such, might be anticipated to underestimate the overall distances travelled. A further 9.2 percent of patients provided an estimate of the distance travelled in place of a postcode. The remainder of the patients did not provide data regarding the distance travelled to their dialysis facility. These patients were excluded from the data used in this study.

After exclusion of incomplete datasets, data for a total of 11,211 patients were available for further analysis. For each of these patients, an emissions factor appropriate to their modality of travel was applied to the distance travelled for both the outward and homeward legs of the journey. In this way, the overall emissions attributable to the travel of the 11,211 ICHD patients to and from their dialysis facility were determined, from which the average emissions per patient was established. This was then multiplied by 156, the number of dialysis treatments received per year by a patient attending thrice weekly, to calculate the emissions associated with the travel of a typical patient to and from ICHD each year.

The advantages of using data collected for the Kidney Care Patient Transport Audit include the large patient numbers, the geographical scope, and the inclusion of travel modality data [Health and Social Care Information Centre, 2010]. No alternative data were identified that would better represent the travel undertaken by ICHD patients in the United Kingdom. Furthermore, it would be beyond the scope of this report to collect more accurate data prospectively. However, it should be noted that this methodology does not account for the fact that some patients will travel to their dialysis facility together. This occurs most commonly when hospital transport vehicles are used. However, any overestimation in the emissions attributable to patient travel to ICHD is likely to be compensated for by the underestimation resulting from calculating the distances ‘as the crow flies’ rather than by road.

Staff Commuting for ICHD

It has been assumed that the distance travelled by staff commuting to work at a dialysis facility was 8.7 miles each way, which was found to be the average distance commuted to work from a sample of 19,490 people in the national travel survey 2006 [Department of Transport, 2006].

It has been assumed that the breakdown of the modalities of travel utilised by staff when commuting to ICHD facilities would be similar to that of United Kingdom commuters in general, and have therefore determined this breakdown from data reported by the National Travel Survey 2006 [Department of Transport, 2006]. It has been assumed that 14% of journeys were made by active travel (walking or cycling), 71% were made by car (or motorbike), 7% were made by bus and 7% were made by rail.

In order that staff travel emissions may be appropriately apportioned, the following assumptions have been made.

One dialysis staff nurse will typically simultaneously provide care to 3 patients undergoing ICHD, and will therefore provide care to 6 patients undergoing haemodialysis in the course of a single nursing shift. The travel emissions of one dialysis nurse are therefore divided between 6 patients.

An in-centre dialysis facility will require one technician, one member of the administration staff, and two members of the domestic staff, to attend each day. The travel emissions of each of these members of staff are therefore divided between 45 patients.

Patient and Staff Travel for HHD

It has been assumed that a patient will undertake quarterly return travel to their local dialysis facility for review by a doctor (a process assumed, for those patients undertaking ICHD, to coincide with one of their routine attendances for ICHD). It has been assumed that no domestic or administration staff travel is necessary. It has been assumed that a renal technician visits a HHD patient every 6 months (once for annual electrical safety checks and preventative maintenance and once for equipment failures), and that a dialysis nurse visits a HHD patient every 3 months. It has been assumed that these staff members travel to and from the patient's local dialysis facility. For both patients and staff, this distance has been assumed to be equal to that of the average distance travelled by a patient receiving ICHD, and has been determined from the Patient Transport Survey Report undertaken as part of the National Kidney Care Audit [Health and Social Care Information Centre, 2010]. It has been assumed that this travel is undertaken exclusively by car.

Building Energy Use

Electricity Consumption

The electricity used by the water systems (in the water treatments, water storage and loop disinfections) and by the haemodialysis machines (in each of the different phases of a treatment session) has been determined for the different regimes and modalities of dialysis. DEFRA emissions factors have been applied to these activity data [DEFRA, 2009].

Electricity Consumed by Water Treatment Systems in ICHD Facilities

The water treatment system in place at the Dorset County Hospital haemodialysis facility has been used to inform the assumptions and facilitate the direct measurements necessary during the collection of activity data.

A pump is used to pressurise mains water. This has been assumed to have a 1.5 kWh motor and to run at 90% capacity for 20 hours a day. It has been assumed to idle for the remaining four hours, during which time power consumption has been assumed to be negligible. The electricity drawn by the pump and attributable to the provision of 156 ICHD treatments to a single patient over the course of one year has been calculated to be 153 kWh (Appendix 6).

The water pre-treatment system has been assumed to consume a negligible amount of energy. Data for the electricity consumption of the reverse osmosis system has been based upon that of a system in which two Gambro 104s reverse osmosis plants run in tandem, drawing a combined total of 5 kWh. It has been assumed that they run for 17.25 hours and 14.25 hours on alternate days, six days a week, in order to provide 165 patient treatments per week. It should be noted that this set-up is slightly over-powered for the number of treatments it is delivering (in order to facilitate expansion) and it is possible that reverse osmosis systems in other units may be more efficient. It should also be noted that energy consumption would be anticipated to be less in those dialysis facilities with variable or ‘demand-dependent’ reverse osmosis systems (rather than fixed power systems). The electricity drawn by the reverse osmosis system and attributable to the provision of 156 ICHD treatments to one patient over the course of one year has been calculated to be 447 kWh (Appendix 6).

Electricity Use Water Storage Systems in ICHD Facilities

In most dialysis facilities, the purified water used to provide dialysate for haemodialysis treatments arrives at the haemodialysis machines by direct feed from the reverse osmosis system, whilst the purified water used for loop disinfections is heated and stored in a tank. For the purposes of this study, it has been assumed that the purified water used for loop disinfections is stored in a 330 litre tank and that this water is delivered to the tank at room temperature. Energy is therefore required to heat this water from room temperature to 60 °C. Storage tanks are supplied in standard sizes and, in most dialysis facilities, a significant volume of unused water remains in the tank after each loop disinfection. This water is cooling from 90 °C at the time that the new water enters the tank. The energy required to heat the new water to 60 °C has therefore been assumed to come from its mixing with the water already in the tank, and no further electricity consumption has been attributed.

In order to maintain the stored water temperature above 60 °C, it has been assumed that the water is heated to 63 °C eight times each day (and allowed to cool spontaneously) on six days of the week, and six times on the day of the 'loop disinfection' cycle. Making the assumption that the process is 100% efficient, the energy required for this process has been calculated using the formula *Energy Used = C x M x Δ T*, where: C = specific heat capacity of water (4.19 J g^{-1} K^{-1}); M = the mass of water being heated, in g (330 litres of water equates to 330 kg or 330,000 g); and ΔT = the change in temperature required, in °K or °C (3 °C). The energy attributable to storing heated water to provide one patient with one year of ICHD treatment (156 sessions) has been calculated to be 59 kWh (Appendix 6).

Electricity Use during Loop Disinfection in ICHD Facilities

During the periodic 'loop disinfections', the stored water is heated from 60°C to 90 °C and pumped through the pipe-work supplying the haemodialysis machines. It has been assumed that loop disinfection is undertaken on a weekly basis and that the process described is 100% efficient. The energy required to heat the water has once again been calculated using the formula *Energy Used = C x M x Δ T,* where *ΔT* is now equal to 30 °C. The energy use attributable to the loop disinfections entailed in the provision of ICHD to one patient for one year has been calculated to be 12 kWh (Appendix 6).

Electricity Use during the Treatment and Storage of Water for HHD machines.

Standard HHD Machines

When used to provide HHD, standard haemodialysis machines are commonly fitted with a dedicated reverse osmosis system providing purified water for dialysate and disinfection on demand. No energy is therefore consumed in the storage (ie heating or pumping) of this water. The electricity used by the reverse osmosis system has been included in the energy consumption of the haemodialysis machine.

Mobile HHD Machines

Purified water may be stored for up to 72 hours in disposable containers ('SAKs') for use by mobile HHD machines. No disinfections or heating are undertaken. The energy consumption of the water purification system has been included in the energy consumption of the haemodialysis machine.

Electricity Use by Standard Haemodialysis Machines during the Provision of ICHD

Assumptions about the manner or pattern of the use of haemodialysis machines to provide ICHD have been based on the practices undertaken in the Dorset County Hospital dialysis facility. Mention has been made of any areas in which these data might not be considered typical of the majority of United Kingdom dialysis facilities.

Activity data for electricity consumed by standard haemodialysis machines have been determined from a number of sources:

The electricity consumption, for each of the component stages of a dialysis treatment (heat disinfection, priming, 4 hour treatment, combined heat and citrate disinfection and chemical disinfection), have been measured during simulated treatments for 3 of the most commonly used brands and models of standard haemodialysis machines:

1. a single Fresenius 5008 machine presently in use at Dorset County Hospital

2. a single Gambro AK200S machine presently in use at Dorset County Hospital. The data collected for this machine were validated by comparison with data published by the manufacturer.

3. five B-Braun Dialog+ machines (with heat exchangers) presently in use at the Maidstone dialysis facility (these data were originally collected for a separate study [Campbell et al, 2010]).

The electrical energy used was measured directly using a power monitor fitted between the wall socket and the machine plug. The data from the Fresenius and Gambro machines were combined with averaged readings from the five B-Braun machines to provide a dataset considered to be representative of a standard haemodialysis machine used in a United Kingdom dialysis facility.

Electricity Use by Standard Haemodialysis Machines during the provision of HHD

Using an identical methodology to that outlined above, the electricity consumption has been measured for a single Gambro AK200S machine set up in the manner used for HHD. The electricity consumption of the portable reverse osmosis system (Gambro WRO300C) has been measured separately. The measurements have been validated against the basic information provided for machines produced by four separate manufacturers [Centre for Evidence-based Purchasing, 2010].

Electricity Use by Mobile HHD Machines during the provision of HHD

The electricity consumption has been determined for the different stages of the two different treatment scenarios used by patients when dialysing with the NxStage Mobile HHD machines at home or whilst travelling (Table 15).

Table 15. The different treatment stages for which the electricity consumption of the NxStage equipment has been measured.

Treatment Stage		Active Devices	Stage Duration
1.	Standby mode.	NxStage Pureflow^{TM} SL device.	Assumed to be 15 minutes. Not included when patient dialyses away from home.
2.	Dialysate production (assumed to be required prior to alternate treatments undertaken at home).	NxStage Pureflow^{TM} SL device.	6 hours. Not included when patient dialyses away from home.
3.	Standby mode.	NxStage Pureflow^{TM} SL device & NxStage System^{TM} One machine.	The Pureflow^{TM} SL device has been assumed to be in standby at all times that dialysate is being stored but no treatment is being administered, in order to heat the dialysate. This is estimated at 93 hours a week for the 5.5 weekly (3 hour treatment) regime, and 84 hours a week for the 6 nightly (7 hour treatment) regime.
4.	Priming of the cassette.	NxStage Pureflow^{TM} SL device & NxStage System^{TM} One machine.	15 minutes.
5.	Treatment session.	NxStage Pureflow^{TM} SL device & NxStage System^{TM} One machine.	3 or 7 hours.
6.	Draining the dialysate from the PAK (required after alternate treatments).	NxStage Pureflow^{TM} SL device & NxStage System^{TM} One machine.	Assumed to take 1 hour.

The electrical energy used during each stage was determined from measurements taken during a simulated treatment using a power monitor fitted between the wall socket and the machine plug. A single set of measurements were taken from a single machine at the Lister Hospital, Stevenage, on July 20th 2010. Where possible, these data were validated by comparison with limited data published by the United Kingdom suppliers for NxStage.

Water Consumption

The volume of pure water required to provide one haemodialysis treatment has been determined from the water required for each of the stages of a haemodialysis treatment (priming, heat disinfection, treatment, combined heat and citrate disinfection, and bleach disinfection). For each haemodialysis modality and regime, these data have then been uplifted in accordance with the efficiency of the reverse osmosis system in place. Finally, any additional water consumption (such as pre-treatment systems) has then been considered. DEFRA emissions factors have been applied to these activity data [DEFRA, 2009].

For patients using standard haemodialysis machines, dialysate flow rates have been assumed to be 300 millilitres per minute for those undertaking 7 hour long treatments, and 600 millilitres per minute for all other patients.

Water Consumption in ICHD Facilities

The water pre-treatment system has been estimated to use 1400 litres of water per week (carbon filter 200 litres per week, water softener 200 litres per day six days per week).

Data regarding water use during the priming and treatment phases of a dialysis treatment provided by a standard haemodialysis machine have been determined from:

1. assumptions, outlined previously, regarding the duration of the priming phase,

2. the differing durations of the treatment phases across the different regimes included in this study,

3. an assumed dialysate flow rate of 600 millilitres per minute.

The resulting data have been uplifted to reflect the assumption that the reverse osmosis systems in ICHD facilities will reject 40% of all water presented to them.

The water consumed during the heat disinfections, combined heat and citrate disinfections and chemical disinfections, has been measured during simulated treatments for 2 of the more commonly used brands and models of standard haemodialysis machines (a Fresenius 5008 machine and a Gambro AK200S machine), both presently in use at Dorset County Hospital. Where possible, the data collected have been validated by comparison with data published by the manufacturer. Once again, the readings have been uplifted to reflect the assumption that the reverse osmosis systems in ICHD facilities will reject 40% of all water presented to them.

Water Consumption during HHD using Standard Haemodialysis Machines

Data regarding water use during the priming and treatment phases of a dialysis treatment provided by a standard haemodialysis machine used to provide HHD have been determined using a similar approach to that described above. However, the resulting data have been uplifted to reflect the assumption that the reverse osmosis systems in HHD facilities will reject 40% of all water presented to them.

The water consumed during the heat disinfections, combined heat and citrate disinfections and chemical disinfections, has been measured during simulated treatments using a Gambro AK200S machine. Where possible, the data collected has been validated by comparison with data published by the manufacturer. Once again, the readings have been uplifted to reflect the assumption that the reverse osmosis systems in ICHD facilities will reject 40% of all water presented to them.

It has been assumed that no water is consumed by pre-treatment processing.

Water Consumption during HHD using Mobile Haemodialysis Machines

The water consumption for the provision of a year of HHD using the two regimes for Mobile haemodialysis machines included in this study has been calculated on the basis of the number of treatments undertaken and the assumption that each treatment requires 30 litres of mains water. The emissions attributable to the use of pre-packaged fluids are included within their procurement, and therefore only those treatments for which the dialysate has been derived from mains water are included in the determination of water consumption. No uplift factor has been applied as no reverse osmosis system is utilised.

Procurement

Medical Equipment

Calculation of Procurement Emissions

The ability of renal services to provide haemodialysis to increasing numbers of patients has been dependent upon the availability of single-use, pre-packaged items of medical equipment. Emissions arising from the production, consumption and disposal of these consumables are included in this study.

Emissions associated with the consumption of these goods are included within the sectors of building energy use and travel. Emissions arising prior to the consumption phase (emissions arising from the point of extraction of the raw materials, the manufacture of the goods and packaging, and their transport to the site of use), and from waste disposal (emissions arising from the collection, treatment and disposal of these items and their packaging), are included within the 'medical equipment' and 'waste' subsectors of the procurement emissions respectively.

Calculating Medical Equipment Procurement Emissions from Economic Activity Data

Emissions arising from the procurement of medical equipment have been shown in the preceding chapter to contribute significantly to the carbon footprint of a renal service, and have been determined through the application of emissions factors to economic activity data. However, the following reservations were identified when considering the adoption of a similar approach in this study.

Firstly, neither of the two sets of emissions factors currently available for medical equipment are specific to the needs of this study [Sustainable Development Commission, 2008; DEFRA, 2009]. Although, in Chapter 4, it has been shown that the DEFRA emissions factors are applicable to the medical equipment used by a renal service, the inventory of medical items used in the provision of haemodialysis is far more refined than in a renal service as a whole, and the use of these factors might be anticipated to introduce unacceptable levels of error.

Secondly, the financial costs of the consumables required to provide haemodialysis are influenced not only by the costs incurred in their production but also by other factors. Hence, the costs of the consumables used in the mobile dialysis technologies, which have only recently been introduced to the United Kingdom market, might be influenced by both the increased marketing expenses of launching a new modality and also the reduced overall expense to the purchaser of a system of care in which patients undertake far less travel for their treatment and use less hospital resources.

In short, the economic costs of the consumable items of medical equipment required for the different modalities of haemodialysis considered in this study cannot be anticipated to reflect the emissions attributable to the respective products with equivalent accuracies. For these reasons, the emissions attributable to the procurement of the medical equipment have been determined from physical activity data collected for their constituent materials (which will be referred to as 'the constituent materials method' hereafter). This decision is supported by a comparison of the use of the two methods to determine the medical equipment emissions arising from a single treatment session delivered with a standard haemodialysis machine (Appendix 7).

The Constituent Materials Method for Calculating Medical Equipment Procurement Emissions

An inventory of the items of medical equipment required to provide a single treatment for each of the modalities of haemodialysis was created, and a similar inventory was created for the packaging of these items (Appendices 4 & 5).

Each item, and its packaging, was weighed, and the contributions of the constituent materials to this weight were either determined or, occasionally, estimated. Emissions factors relating to this material were then applied to convert these weights to CO_2 emissions. These emissions factors were taken from the independent ICE database (see Chapter 4, under the heading The Choice of Emissions Factors, for a description of this database) [Hammond & Jones, 2008].

It is important to consider the boundaries used in the determination of the embodied carbon of a material within this database, in order to ensure consistency with the approach undertaken in this study. In many cases, the ideal boundaries might be 'cradle to grave' (beginning at the point of extraction of the raw material, encompassing the emissions arising from interim processes such as manufacture, transport, and use, before ending at the point of disposal). For the purposes of this study, in which the emissions associated with the use and disposal stages of the life-cycle of medical equipment (and, therefore, its constituent materials) are considered separately, the optimal boundaries might be 'cradle to site' (which includes all emissions until the product arrives at its point of use). However, within the ICE database, the boundary conditions for the materials of interest for this study were specified as 'cradle to gate' (which includes all emissions until the product leaves the factory). Given that these materials have relatively high embodied carbons (ie high embodied energies and densities) in comparison to those of, for example, aggregates and sand, it might be argued that the difference between the embodied carbon when measured from 'cradle to gate' or 'cradle to site' might be considered negligible.

When applying the ICE data, particular care has also been taken to ensure consistency between the recycling methodology quoted within ICE for each material and boundaries of this study. The exclusive use of ICE data within the procurement sector of this study is anticipated to have further reduced the chances of mixing recycling methodologies.

The model used in this study therefore assigns the carbon embedded in items of medical equipment to their manufacture and, as such, it is included within the emissions attributable to their procurement (with the emissions associated with their disposal being considered separately). However, the manufacture of a given quantity of a product is likely to require more than this quantity of material. The extent of manufacturing waste, and what happens to it (re-use, recycling or disposal) has been excluded from this study. Furthermore, some highly fabricated and intricate items of medical equipment will have energy-intensive manufacturing processes, but more detailed exploration of this has been considered to lie outside the scope of this report.

Therefore, in recognition of the emissions resulting, firstly, from the material wastage and energy use during the manufacturing process, and, secondly, during the transportation of the raw materials and final products, an uplift factor of 10% has been applied to the emissions determined by the constituent materials method for the procurement of the items of medical equipment required to provide haemodialysis.

Assumptions made regarding Consumables and their Constituent Materials

The ICE database provides emissions factors for the CO_2 emissions alone. The GHG emissions of a constituent material have therefore been assumed to be commensurate with the CO_2 emissions. This approach undoubtedly underestimates the overall GHG emissions arising from medical equipment. However, the extent of this underestimation is anticipated to be small, as the products are almost exclusively produced from plastics and metals.

ICHD and HHD using Standard Haemodialysis Machines

The emissions attributable to the procurement of the pharmaceutical grade fluids (saline, acid and alkalis) required to provide a haemodialysis treatment have been determined from economic activity data and the application of DEFRA emissions factors for pharmaceuticals [DEFRA, 2009].

It has been assumed that the acid for ICHD will be delivered in canisters rather than by a central acid delivery system.

Mobile HHD Technologies

The canisters in the PAK contain an ion exchange resin (assumed to be polyethylene) and activated carbon. In the absence of data regarding the embedded carbon in the activated carbon used for medical purposes, it has been assumed that it is a product of combustion (rather than, for example, acid washing) and have taken an average of the embedded carbon in three other materials produced by combustion (lime, clay tiles, and cement). The ion exchange resin and activated carbon have been assumed to be present in equal proportions. It has been assumed that a new PAK is required every 10 weeks.

For patients using the Mobile HHD systems, it has been assumed that one 'SAK' will be used for every two treatments. Although some patients may require a dialysis dose sufficiently small that three treatments may be provided from the dialysate produced in one 'SAK', it was anticipated that these patients would be in the minority. Furthermore, as the dialysate within one 'SAK' must be used within 72 hours, there will be occasional wastage.

The pre-packaged fluid bags have been assumed to be made from the same combination of plastics as the one litre saline bags. Their packaging has been assumed to be polythene. The tubing has been assumed to be made from polyvinylchloride.

It has been assumed that five, five-litre, pre-packaged, fluid bags will be required to provide one three hour treatment.

Assumptions made regarding patient travel for non-medical reasons (and the relationship of this travel with the procurement emissions)

The emissions arising from patient travel to and from their dialysis facility have already been considered. However, patients may travel away from their home for other reasons. Such travel may influence one or both of their dialysis modality and regime, and impact upon the procurement emissions.

Patients Using Standard Haemodialysis Machines

Although patients undertaking ICHD can undertake haemodialysis at alternative dialysis facilities, such 'holiday dialysis' is uncommon (less than one week per year for most patients), and is not anticipated to significantly influence the emissions attributable to their haemodialysis as the modality (ie ICHD) remains unchanged.

The size and weight of standard haemodialysis machines is such that patients using them for HHD must organise 'holiday dialysis' sessions (essentially ICHD at a non-local dialysis facility) in order to travel. Again, as the availability of 'holiday dialysis' is extremely limited, this is not anticipated to significantly influence the emissions of patients undertaking HHD with standard machines.

Patients Using Mobile HHD Machines

Conversely, the size and nature of the Mobile HHD NxStage equipment is such that patients can travel more easily. However, the consumables used by such patients when away from home will vary. For these reasons, travel must be incorporated. It has been assumed that a patient undertaking Mobile HHD will holiday away from home for 3 weeks of the year, and travel away from home for two nights every third week. When away from home, it has been assumed that they will undertake short daily dialysis using pre-packaged fluid bags.

For a patient following the NxStage nocturnal dialysis regime (7 hr sessions, six nights a week), this equates to 279 nocturnal treatments (all undertaken at home, using dialysate produced by the Pureflow system), 48 short (3 hour) treatments (all undertaken away from home, using dialysate from pre-packaged fluid bags), and 37 days without dialysis.

For a patient following the NxStage short daily dialysis regime (3 hr sessions, 5.5 days a week), this equates to 286 short daily treatments (an average of 5.5 per week), of which 253 will be undertaken at home (using dialysate produced by the Pureflow system) and 33 will be undertaken away from home (using dialysate from pre-packaged fluid bags). These patients will have 78 days without dialysis.

Waste

The use of disposable, pre-packaged, items of medical equipment during haemodialysis results in the production of waste. The collection, treatment and disposal of this waste contribute to the carbon footprints of the different haemodialysis regimes. The model used in this study assigns the carbon embedded in products and packaging to the manufacturing process, and it is therefore included within the emissions attributable to their procurement. It is important that this carbon is not then 'double counted' during the calculation of the emissions arising from the disposal of these products and packaging. Therefore, the 'end of life' carbon footprint has been calculated using the DEFRA emissions factors for waste treatment processes [DEFRA, 2009], as opposed to the sum of the 'end of life' and 'production' carbon footprints.

Waste arising from haemodialysis is categorised as being either clinical or domestic waste. The results of the survey reported in Chapter 3 illustrated that waste management strategies and practices vary amongst renal services, and optimal practice is rarely attained. Although newer technologies are emerging for the disposal of clinical waste, at present this waste is almost always incinerated. However, it is not uncommon for some domestic waste to undergo incineration as well, although, for most items of domestic waste, the optimal method of waste disposal is probably recycling, with the remainder being sent to landfill. The majority of packaging waste (cardboard, paper and plastic film) is recyclable although, in practice, it is rarely recycled.

Primary activity data, in the form of the weight and constituent materials of the waste produced for each haemodialysis regime, have been identified by direct measurement (Appendices 4 and 5).

Given the known variability in waste management strategies and practice, and the absence of published studies reporting current practice to the detail required for this study, it has been assumed that optimal waste management strategies are implemented within reasonable and practical limits. Therefore, for standard haemodialysis machines, it has been assumed that: all blood lines, dialysers, fistula needles, syringes, gloves, aprons, kidney dishes and gauze packs undergo incineration; all intravenous fluid bags, intravenous administration sets, bicarbonate cartridges (or bags), and plasters are sent to landfill; and all packaging, acid canisters and paper towels are recycled. For mobile HHD machines, it has been assumed that: the disposable filter system (PAK) is sent to landfill (although some components are recyclable, it is impractical for staff or patients to break down the outer casing and segregate the components); the cartridge (containing the dialyser, blood lines, cassette tray and a plastic wallet) is incinerated (although some components, are recyclable, the nature of the product again renders a segregation approach impractical); the SAK is sent to landfill as it is not currently recyclable (information provided by Kimal plc, United Kingdom distributor for NxStage, by email, June 1st, 2010); the pre-packaged fluid bags are sent to landfill (in the absence of data indicating that they are recyclable); all packaging is recycled; and all fistula needles, syringes, gloves, aprons, kidney dishes and gauze packs undergo incineration.

DEFRA emissions factors have been applied to the activity data collected for waste.

Construction

The emissions arising from both the installation and maintenance construction work required to ensure dialysis environments are fit for purpose were determined from activity data that were economic and secondary (determined by methods other than direct measurement) in nature, and to which DEFRA emissions factors were applied [DEFRA, 2009]. Economic data were used as physical data was not available.

Installation Construction Work for ICHD

Due to differences in size, property costs and potential for future expansion, considerable variation exists within the financial costs reported for the construction of new satellite dialysis facilities in the United Kingdom. The average cost, per dialysis station, of the 11 satellite dialysis facilities that opened during 2006 was £47,890 [Department of Health, 2007]. Assuming inflation rates have averaged 2.5% between 2006 and 2009, this equates to a cost of £51,659 (calculated at http://www.bankofengland.co.uk/education/inflation/calculator/flash/index.htm).

A typical dialysis station has been assumed to provide two and three treatments per day on alternate days, six days per week, equating to 780 treatments per year. Assuming a depreciation period of 20 years, the initial financial outlay of £51,659 per station therefore provides 15,600 treatments - a cost per treatment of £3.31147. A patient receiving ICHD undergoes 156 treatments per year. The financial cost attributable to the construction work required to set up an ICHD facility has therefore been calculated to be £516.59 per patient per year.

DEFRA emissions factors have been applied to the economic activity data for installation construction [DEFRA, 2009].

Maintenance Construction for ICHD

Emissions data relating to maintenance construction were calculated from estimations derived from data provided by the Dorset County Hospital Estates Department detailing the expenditure per square metre on maintenance construction, and DEFRA emissions factors. It has been assumed that this data is representative of the expenditure per square metre for a dialysis facility. A typical dialysis facility has been assumed to be 270 square metres and to provide 225 treatments per week.

Installation Construction Work for HHD using Standard Machines

Pre-existing accommodation, that may be rendered suitable for the provision of HHD using standard haemodialysis machines with only minor construction work, is presently often a prerequisite for patients to be considered for HHD in many renal services. Therefore, the emissions associated with any installation construction work are likely to represent only a small proportion of the overall emissions attributable to the provision of HHD. Nevertheless, these emissions have also been included in this report.

In the absence of published data, the installation cost, per patient home, has been estimated at £3000 on the basis of informal reports from individual renal services. The depreciation time has been assumed to be 5 years, a figure chosen to reflect a balance between the results of an analysis of data from the Renal Registry (showing that half of patients commencing HHD in the United Kingdom will receive a transplant within 20 months) and the four-fold reduction in life-expectancy of patients on maintenance haemodialysis [Ansell, 2008; United States Renal Data Systems, 2007]. Economic activity data, in the form of the financial cost attributable to the installation construction work required per HHD patient per year, have been calculated and DEFRA emissions factors have been applied to this [DEFRA, 2009].

Maintenance Construction Work for HHD using Standard Machines

As the room in which patients undertake HHD commonly becomes dedicated to the provision of haemodialysis, and is often no longer available for other activities of daily living, the emissions attributable to the maintenance of the room, including the necessary plumbing, electrical and structural modifications, have been included in this study and are estimated to be £100 per patient per year. DEFRA emissions factors have been applied to this economic activity data.

Installation Construction Work for HHD using Mobile HHD Technologies

The nature of the mobile HHD technologies is such that it has been assumed that no plumbing, electrical or structural modifications are required for this modality and, as such, the emissions attributable to setting up the environment have been considered to be negligible.

Maintenance Construction Work for HHD using Mobile HHD Technologies

Although it is perhaps less common for the room in which patients undertake HHD to be dedicated solely to the provision of haemodialysis when mobile HHD technologies are used, the emissions attributable to maintenance construction for such a room have again been included in this report, however, as there are no plumbing, electrical or structural modifications, the costs have been estimated at just £50 per patient per year. DEFRA emissions factors have been applied to this economic activity data.

Laundry

Emissions attributable to the laundry resulting from haemodialysis treatments have been considered to arise from transport (to private laundry companies, in the case of ICHD), washing and drying.

ICHD

HD treatments may have a cooling effect on core body temperature, and it has been assumed that half of patients undertaking ICHD will choose to cover themselves with a blanket. Dialysis stations are used repeatedly by different patients and it has been assumed that half of ICHD facilities will cover each station with a new sheet prior to a patient's treatment (with the remainder assumed to have vinyl 'wipe clean' stations). Based upon these assumptions, the weight of linen laundered per patient per year was calculated from direct measurements.

It has been assumed that all laundry requirements arising from the provision of ICHD will be contracted out to private laundry companies (as most hospitals now have small, or no, laundry departments, and no satellite dialysis units were considered unlikely to launder their linen on site). It has been assumed that the laundry travels in rigid, diesel, heavy goods vehicles which run at the United Kingdom average capacity. It has been assumed that the one way distance between the dialysis facility and the laundry service is 8 miles (based upon data from a sample of dialysis facilities in Dorset and Somerset). As the Dorset Renal Service laundry forms a component of the local sites overall laundry burden, it has been assumed that the number of journeys made is equivalent to the total weight of laundry produced per year, divided by the maximum capacity of the vehicles used.

In the absence of more accurate data, it has been assumed that the washing and drying machines have energy efficiencies, per kg load, equivalent to that of standard domestic machines.

HHD

It has been assumed that patients undertaking HHD will not use a sheet. It has been assumed that only one quarter of patients undertaking HHD will use a blanket, and that this will be washed in the own home once a fortnight, and dried using a drying machine in 25% of cases.

Paper and Office Supplies

The emissions attributable to the procurement of paper and office supplies are calculated from economic activity data. The annual expenditure of the Dorset County Hospital haemodialysis Department on paper, and office supplies (including printer cartridges) was determined for 2008/09 from the records of the Procurement Department at Dorset County Hospital. Office supplies were further sub-divided into machinery, plastic goods and metal goods. DEFRA supply chain emissions factors were applied to these data [DEFRA, 2009]. The emissions per treatment were determined by dividing the total emissions arising from the procurement of paper and office supplies by the number of haemodialysis treatments provided annually. The emissions per treatment were then extrapolated up for each haemodialysis regime, on the basis of the number of treatments provided annually. It was assumed that the emissions, per treatment, attributable to paper and office supplies are similar for ICHD and HHD.

Sanitation Products

It has been assumed that both standard and mobile haemodialysis machines require external decontamination after every treatment session. It has been assumed that the machines are first cleaned using a wipe soaked in detergent (diluted from concentrate), before being disinfected using 70% isopropyl alcohol wipes. It has been assumed that the amount of these products required will be similar for all types of haemodialysis machine.

Primary activity data, by way of the annual expenditure on these cleaning products, have been determined from the Procurement Department records for the Dorset County Hospital haemodialysis unit for 2008/09, from which the cost per treatment has been calculated. DEFRA emissions factors have been applied to these data [DEFRA, 2009].

Dialysis Access Surgery

The use of central venous catheters as haemodialysis access results in the use of very slightly higher rates of consumables during each dialysis treatment. However, in the United Kingdom, only 22% of patients receiving maintenance haemodialysis do so via a central venous catheter [Oxford Handbook of Dialysis, 2009]. For the purposes of this study, it has therefore been assumed that all patients dialyse through arteriovenous fistulae.

The data sources and assumptions used when considering the emissions attributable to dialysis access surgery are outlined below.

It has been assumed that fistula surgery is undertaken as a day case procedure under local anaesthetic. It has been assumed that a patient will spend 6 hours on the day case ward and one hour in theatre and recovery.

The distance and modality of travel, for patients attending for access surgery, have been assumed to be similar to those of a patient travelling to receive ICHD, and have therefore been determined from the data collated for the Patient Transport Survey Report undertaken as part of the National Kidney Care Audit [Health and Social Care Information Centre, 2010]. DEFRA emissions factors have been applied to these activity data [DEFRA, 2009].

It has been assumed that the distance travelled by the staff directly involved in the access surgery (day case ward nursing and administrative staff, surgeons, anaesthetists, theatre and recovery nurses) was 8.7 miles each way, as this is the average distance commuted to work [Department for Transport, 2006], and that these journeys were all made by car. The emissions of the individual staff members have been determined by the application of DEFRA emissions factors to these activity data [DEFRA, 2009], and allocated in proportion to the number of patients that these staff members have been assumed to care for.

The building energy use per square meter of day case ward and theatre space has been estimated from primary activity data collected from Dorset County Hospital, and the assumptions that the energy use of the day case ward will be comparable to that of the average energy use in Dorset County Hospital, whilst the energy use in theatres will be twice this. DEFRA emissions factors have been applied to these activity data [DEFRA, 2009].

The emissions attributable to the procurement of anaesthetics and surgical equipment and pharmaceuticals have been determined from estimations of the financial cost of these items and the application of DEFRA emissions factors to these economic data [DEFRA, 2009].

It has been assumed that the emissions attributable to the waste produced from one operation are comparable to those of the waste produced by one session of ICHD using a standard haemodialysis machine.

It has been assumed that dialysis access surgery will be unsuccessful in every third patient (to account for primary failures and the failure of some fistulas to mature), but that a second operation will always be successful. It has been assumed that fistula survival will be 4 years and that no interventions are undertaken to achieve this.

From these data sources and assumptions, the emissions attributable to the formation of a functioning fistula have been determined, and this figure has been in terms of emissions per patient year of haemodialysis.

Emissions Factors

The emissions factors used in the calculation of the carbon footprints of the different forms of haemodialysis are provided in the Tables 16,17,18 and 19.

Table 16. The emissions factors applied to staff, patient and visitor travel, and freight transport, activity data.

	Emissions factor to convert to GHG emissions ($kg\ CO_2eq$ per km)
Active travel (walking, cycling)	0.0
Car [a]	0.20487
Taxi [b]	0.15965
Bus [c]	0.10462
Train [d]	0.06113
Ambulance [e]	0.26866
Hospital transport vehicle [f]	0.22608
Freight Transport [g]	0.80201

[a] This emissions factor refers to an average car, running on diesel or petrol, and undertaking average journey lengths in the United Kingdom [DEFRA, 2009].

[b] This emissions factor refers to a regular taxi (not a black cab) in the United Kingdom [DEFRA, 2009].

[c] This emissions factor refers to an average public bus in the United Kingdom [DEFRA, 2009].

[d] This emissions factor refers to an average emission passenger diesel or electric train in the United Kingdom [DEFRA, 2009].

[e] In the absence of a specific emissions factor for travel by ambulance, that of an average van (up to 3.5 tonnes) in the United Kingdom has been used [DEFRA, 2009].

[f] In the absence of a specific emissions factor for travel by hospital transport vehicle (as opposed to car, taxi or ambulance), that of a multiple person vehicle in the United Kingdom has been used [DEFRA, 2009].

[g] This emissions factor, which refers to the average rigid (non-articulated) heavy goods vehicle in the United Kingdom, was used to calculate the emissions relating to the transport of laundry to privately run, off site, laundry services [DEFRA, 2009].

Table 17. The emissions factors applied to building energy use activity data.

	Emissions factor to convert to GHG emissions (kg CO_2eq per kWh)
Electricity	0.50748 [a]

[a] These emissions factors refer to the conversion of purchased electricity to GHG emissions [DEFRA, 2009].

Table 18. The emissions factors applied to procurement activity data.

	Emissions factor to convert to GHG emissions
Constituent Materials of Medical Equipment & Packaging	
General Plastics	2.53 kg CO_2 per kg [b]
Low density polyethylene	1.7 kg CO_2 per kg [b]
High density polyethylene	1.6 kg CO_2 per kg [b]
General polyethylene	1.94 kg CO_2 per kg [b]
Polypropylene	2.7 kg CO_2 per kg [b]
Polyurethane	3 kg CO_2 per kg [b]
Polycarbonate	6 kg CO_2 per kg [b]
Polyvinylchloride	2.41 kg CO_2 per kg [b]
Paper	1.5 kg CO_2 per kg [b]
Stainless steel	6.15 kg CO_2 per kg [b]
Rubber	3.18 kg CO_2 per kg [b]
Copper	3.83 kg CO_2 per kg [b]
Activated Carbon (Polymer coated)	0.67 kg CO_2 per kg [c]
Pharmaceuticals	0.80 kg CO_2 per £ [a]
Cardboard	1.32 kg CO_2 per kg [b]
Construction	0.54 kg CO_2eq per £ [a]
Water	0.276 kg CO_2eq per m^3 [a]
Plastic Products (Office Supplies)	1.13 kg CO_2eq per £ [a]
Metal Products (Office Supplies)	1.18 kg CO_2eq per £ [a]
Office Machinery and computers	0.58 kg CO_2eq per £ [a]
Paper Products	1.30 kg CO_2eq per £ [a]
Sanitation Products	0.80 kg CO_2eq per £ [a]

[a] Source of Emissions Factor: DEFRA [DEFRA, 2009].

[b] Source of Emissions Factor: ICE [Hammond & Jones, 2008]. The ICE database provides emissions factors for the CO_2 emissions alone. The GHG emissions of a constituent material have been assumed to be commensurate with the CO_2 emissions.

[c] Assumed to be comparable to the average of embedded carbon in lime, clay tiles and cement (0.74, 0.46 and 0.83 kg CO_2 per kg, respectively [b])

Table 19. The emissions factors applied to waste collection, treatment and disposal activity data.

Waste Disposal Method	Waste Constituent	kg CO_2eq emitted per tonne of waste constituent [a]
INCINERATION	Paper	1800 [b]
	Plastics	
	Rubber	
	Metal	
RECYCLING	Paper	-713
	Plastics (film)	-1000
	Plastics (dense)	-1500
	Cardboard	-713
LANDFILL	Plastics	40
	Metal	10

[a] Emissions factors from DEFRA [DEFRA, 2009].

[b] DEFRA emissions factors for incineration of different materials do not account for the incineration of clinical waste, which must be undertaken at higher temperatures [DEFRA, 2009]. To reflect the increased emissions that are likely to result from the incineration of clinical waste, the highest available emissions factor for incineration was applied to each of the constituents.

Data Accuracy

When calculating a carbon footprint, measures should be taken to ensure that all input, output and waste streams are accounted for and that no 'double counting' of emissions has occurred. Whilst a common approach to this is to undertake a 'mass balance', the mix of economic and physical data collected in this study renders this approach impractical. This problem, which is relatively common when calculating the carbon footprint of a service rather than a product, was therefore surmounted by performing an activity based assessment. For the given activity (an individual haemodialysis treatment), all processes and materials flowing into and out of that activity stage have been analysed for their GHG emissions.

Results

The carbon footprints attributable to the provision of uncomplicated maintenance haemodialysis to a single patient using the differing haemodialysis modalities and regimes are presented in Table 20 and illustrated in Figure 9.

Table 20: The Carbon Footprints of the Provision of Maintenance Haemodialysis to a Single Patient Using Differing Haemodialysis Modalities and Regimes.

		ICHD		Standard HHD (3 x 4 hrs)		Standard HHD (4 x 4.5 hrs)		Standard HHD (5 x 4 hrs)		Standard HHD (6 x 2 hrs)		Standard HHD (6 x 7 hrs)		Standard HHD (3 x 7 hrs)		Mobile HHD (5.5 x 3 hrs)		Mobile HHD (6 x 7 hrs Nocturnal)	
Sector	Sub-Sector	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions	Annual GHG Emissions (kg CO_2eq)	% of Total GHG Emissions
Energy Use		796	*20.8*	1148	*34.7*	1647	*37.9*	1882	*36.8*	1458	*28.0*	3436	*47.8*	1742	*44.7*	169	*9.2*	263	*12.4*
Travel	Staff	175	*4.6*	28	*0.8*	28	*0.6*	28	*0.6*	28	*0.5*	28	*0.4*	28	*0.7*	28	*1.5*	28	*1.3*
	Patient	747	*19.6*	19	*0.6*	19	*0.5*	19	*0.4*	19	*0.4*	19	*0.3*	19	*0.5*	19	*1.1*	19	*0.9*
Procur e-ment	Med Equipment																		
	Consumables	1399	*36.6*	1399	*42.3*	1865	*42.9*	2332	*45.5*	2798	*53.7*	2798	*38.9*	1399	*35.9*	1084	*58.8*	1223	*57.4*
	Packaging	22	*0.6*	22	*0.6*	29	*0.7*	36	*0.7*	43	*0.8*	43	*0.6*	22	*0.6*	26	*1.4*	33	*1.6*
	Water	14	*0.4*	23.3	*0.7*	34	*0.8*	46	*0.9*	32	*0.6*	40	*0.6*	22	*0.6*	2	*0.1*	2	*0.1*
	Paper	7	*0.2*	7	*0.2*	10	*0.2*	12	*0.2*	15	*0.3*	15	*0.2*	7	*0.2*	14	*0.7*	15	*0.7*
	Laundry	53	*1.4*	10	*0.3*	10	*0.2*	10	*0.2*	10	*0.2*	10	*0.1*	10	*0.3*	10	*0.6*	10	*0.5*
	Construction																		
	Installation	279	*7.3*	324	*9.8*	324	*7.5*	324	*6.3*	324	*6.2*	324	*4.5*	324	*8.3*	0	*0.00*	0	*0.00*
	Maintenance	52	*1.4*	54	*1.6*	54	*1.2*	54	*1.0*	54	*1.0*	54	*0.8*	54	*1.4*	27	*1.5*	27	*1.3*
	Sanitation	26	*0.7*	26	*0.8*	35	*0.8*	43	*0.9*	52	*1.0*	52	*0.7*	26	*0.7*	48	*2.6*	52	*2.5*
	Waste Disposal																		
	Clinical (incinerated)	208		208		278		347		417		417		208		313		358	
	Domestic (recycled)	-80	*3.4*	-180	*3.9*	-107	*4.0*	-133	*4.2*	-160	*5.0*	-160	*4.0*	-80	*3.3*	-19	*16.2*	-22	*15.9*
	Domestic (landfill)	1		1		1		1		2		2		1		4		4	
Other Sectors	Access Surgery	30	*0.8*	30	*0.9*	30	*0.7*	30	*0.6*	30	*0.6*	30	*0.4*	30	*0.8*	30	*1.6*	30	*1.4*
	Outpatient Appts	88	*2.3*	88	*2.7*	88	*2.0*	88	*1.7*	88	*1.7*	88	*1.2*	88	*2.3*	88	*4.8*	88	*4.1*
	Total	3818	*100*	3308	*100*	4346	*100*	5121	*100*	5210	*100*	7197	*100*	3901	*100*	1844	*100*	2131	*100*

Figure 9. The carbon footprints attributable to the provision of uncomplicated maintenance haemodialysis to a single patient using the differing haemodialysis modalities and regimes.

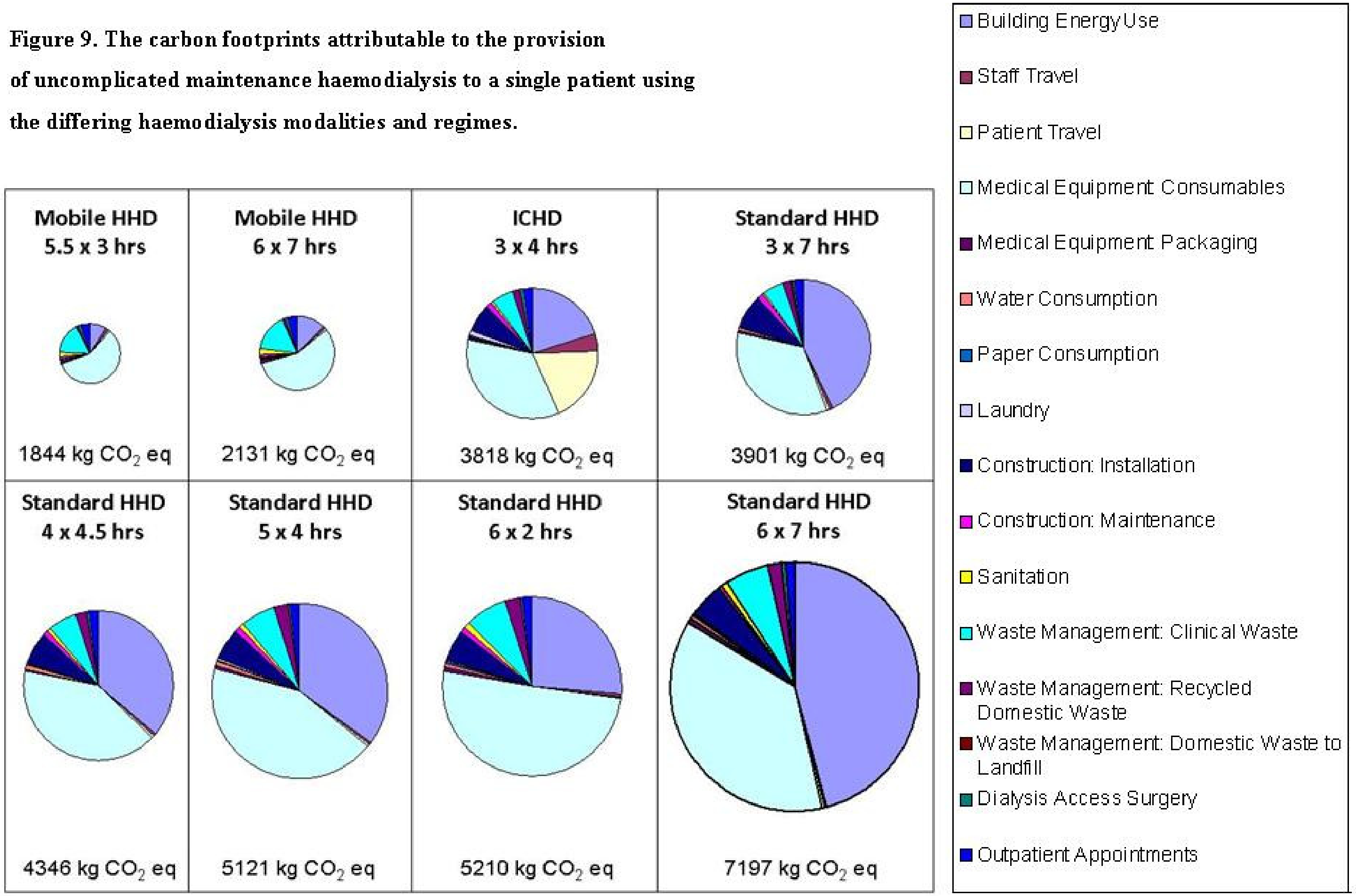


Table 21: The impact of dialyser reuse upon the carbon footprint of thrice-weekly ICHD.

	Single-Use of Dialyser		Dialyser Reuse	
	GHG Emissions (kg CO_2eq)	%age of Total GHG Emissions	GHG Emissions (kg CO_2eq)	%age of Total GHG Emissions
Building Energy Use	796	*20.1*	796	*23.1*
Staff Travel	175	*4.6*	175	*5.1*
Patient Travel	747	*19.6*	747	*21.7*
Medical Equipment				
Consumables	1399	*36.6*	1109	*32*
Packaging	22	*0.6*	18	*0.5*
Water Consumption	14	*0.4*	14	*0.4*
Paper Consumption	7	*0.2*	7	*0.2*
Laundry	53	*1.4*	53	*1.6*
Construction				
Installation	279	*7.3*	279	*8.1*
Maintenance	52	*1.4*	52	*1.5*
Sanitation	26	*0.7*	26	*0.8*
Waste Management				
Clinical Waste	208	*3.4*	129	*1.5*
Recycled Domestic Waste	-80		-78	
Domestic Waste to Landfill	1		1	
Dialysis Access Surgery	30	*0.8*	30	*0.9*
Outpatient Appointments	88	*2.3*	88	*2.6*
Total	3818	*100*	3448	*100*

Table 22. A comparison of the GHG emissions attributable to the provision of thrice weekly, four hour sessions of haemodialysis in the ICHD and HHD (standard and NxStage equipment) settings.

	ICHD (Standard Haemodialysis Machine)		HHD (Standard Haemodialysis Machine)		HHD (NxStage Equipment)	
	GHG Emissions (kg CO_2eq)	%age of Total GHG Emissions	GHG Emissions (kg CO_2eq)	%age of Total GHG Emissions	GHG Emissions (kg CO_2eq)	%age of Total GHG Emissions
Building Energy Use	796	*20.8*	1148	*34.7*	116	*10.1*
Staff Travel	175	*4.6*	28	*0.8*	28	*2.4*
Patient Travel	747	*19.6*	19	*0.6*	19	*1.7*
Medical Equipment						
Consumables	1399	*36.6*	1399	*42.3*	612	*53.1*
Packaging	22	*0.6*	22	*0.6*	17	*1.4*
Water Consumption	14	*0.4*	23.3	*0.7*	1	*0.1*
Paper Consumption	7	*0.2*	7	*0.2*	7	*0.6*
Laundry	53	*1.4*	10	*0.3*	10	*0.9*
Construction						
Installation	279	*7.3*	324	*9.8*	0	*0*
Maintenance	52	*1.4*	54	*1.6*	27	*2.3*
Sanitation	26	*0.7*	26	*0.8*	26	*2.3*
Waste Management						
Clinical Waste	208	*3.4*	208	*3.9*	179	*14.8*
Recycled Domestic Waste	-80		-180		-11	
Domestic Waste to Landfill	1		1		2	
Dialysis Access Surgery	30	*0.8*	30	*0.9*	30	*2.6*
Outpatient Appointments	88	*2.3*	88	*2.7*	88	*7.6*
Total	**3818**	*100*	**3308**	*100*	**1151**	*100*

Discussion

This is the first study to report the individual carbon footprints of a comprehensive range of maintenance haemodialysis modalities and regimes. The most common form of dialysis undertaken by patients in the United Kingdom, thrice weekly ICHD [Byrne, Steenkamp et al., 2010], has a carbon footprint of 3.8 tonnes CO_2eq per patient per year, with the majority of the emissions arising within the medical equipment (37%), building energy use (21%) and patient travel (20%) sectors (Table 20).

Meanwhile, the delivery of HHD using standard haemodialysis machines results in the release of between 3.9 and 7.2 tonnes CO_2eq per patient per year depending on the regime (Table 20). Therefore the choice of regime may have a two fold impact on the carbon footprint. Undertaking a six-nightly nocturnal HHD regime, to which this latter figure relates, is therefore likely to almost double the carbon footprint of a typical United Kingdom resident [Carbon Trust, 2006].

This is also the first study to report the direct and indirect emissions associated with the provision of haemodialysis. The inclusion of indirect emissions - for example, those arising within the supply chains of the consumable items of medical equipment required for haemodialysis – explains, in part, the considerable discrepancy between the results of this study and those of the only previous study to estimate the carbon footprint of haemodialysis treatments [James, 2007].

The results of this study show that the delivery of haemodialysis is associated with considerable GHG emissions. Yet the number of prevalent haemodialysis patients in the United Kingdom continues to rise year on year [Byrne, Steenkamp et al., 2010]. Strategies to reduce the environmental impact of haemodialysis, without compromising the quality of the treatment, must therefore be identified.

Furthermore, although the decline in the proportion of prevalent dialysis patients on HHD is ongoing, the absolute numbers of patients on HHD are no longer falling and, indeed, there is now evidence of a slow increase in these numbers [Byrne, Steenkamp et al., 2010]. This growing momentum is underpinned by evidence that HHD is arguably more cost-effective [Baboolal et al., 2008; McGregor et al., 2000; Honkanen & Rauta, 2008; Mowatt et al., 2003], offers an improved quality of life [Finkelstein et al., 2007; Evans et al., 1985], and confers greater health benefits. With regard to this last point, although robust evidence of improved patient outcomes by way of randomised controlled trials is lacking (primarily as a result of the difficulties presented by the selection bias inherent in comparisons of the outcomes of patients able to train for and perform HHD with the outcomes of other patient groups), the benefits of the more frequent and longer treatment times, that become feasible with HHD, are also increasingly championed by clinicians [Kliger, 2009]. It is to be anticipated, therefore, that not only will the prevalence of patients undertaking haemodialysis increase, but that many of these patients will dialyse more frequently and for longer than is presently the case. So how might this affect the environmental impact of haemodialysis programmes?

This study shows that the reduction in patient travel emissions associated with the provision of HHD offers the possibility of a clinically significant increase in dialysis treatment time beyond that of thrice-weekly ICHD, without a significant increase in the overall emissions. The model of thrice-weekly nocturnal HHD offers 9 hours more dialysis per week than ICHD, yet the two regimes have comparable carbon footprints (3.9 and 3.8 tonnes CO_2eq respectively).

However, the production of medical equipment is carbon intensive, and the reduction in patient travel emissions is soon offset by an increase in the frequency of haemodialysis treatments and the associated increase in the use of equipment. Indeed, the provision of six two-hour HHD treatments per week has a carbon footprint of 5.2 tonnes CO_2eq – considerably greater than the 3.8 tonnes attributable to the delivery of the same total weekly treatment time by thrice-weekly ICHD.

The findings of this study suggest that the rising uptake of HHD, in its current form and using standard machines, is likely to increase, rather than decrease, the carbon footprint of haemodialysis programmes. So, how might the emissions associated with each treatment session be reduced?

Emissions arising within the supply chains of the consumable items of medical equipment contribute significantly to the carbon footprint of the provision of haemodialysis (representing 37% of the emissions associated with ICHD). Although the inclusion of sustainability criteria within the contracts tendered by renal services is anticipated to drive down these emissions over time, shorter term strategies are also required. Opportunities to reduce the items of medical equipment are limited and, although the findings of the survey reported in Chapter 3 suggest that considerable scope exists to implement more sustainable waste management practices within United Kingdom dialysis facilities, the carbon footprints reported here already reflect optimal recycling practice (within the constraints of practicality). However, the possibility of re-using items of medical equipment, and dialysers in particular, might offer more significant environmental benefits [Upadhyay et al., 2007]. Although currently prohibited within the United Kingdom, dialyser reuse remains commonplace within the US, where it has been driven primarily by financial considerations. This is the first study to report the potential reductions in emissions arising from dialyser reuse and to consider them in the context of the overall emissions attributable to haemodialysis.

The re-use of dialysers over 10 treatments reduces the carbon footprint of the provision of thrice-weekly ICHD by 9.7%, from 3818 to 3448 kg CO_2eq per patient per year (Table 21). This significant carbon saving derives not only from reductions in the supply chain emissions of the dialysers (290 kg CO_2eq) and associated packaging (4 kg CO_2eq), but also from reductions in the waste management emissions (primarily a reduction of 79 kg CO_2eq in the emissions attributable to incineration).

Although these calculations exclude emissions arising from re-use related increases in the procurement and disposal of consumables required to reprocess the dialysers (such as gloves, aprons and test strips) and the energy costs of the process itself (which includes heating water), a significant carbon saving remains likely. These results suggest that a full environmental analysis, to better understand the concerns arising from the use of chemicals (including paracetic acid and aldehydes) to reprocess the dialysers, is warranted.

Electricity consumption also contributes significantly to the carbon footprint of the provision of haemodialysis using standard machines, representing 21% and 48% of the emissions associated with ICHD and six nightly nocturnal haemodialysis respectively. With standard machines, the lower electricity consumption of ICHD treatments results primarily from the greater efficiency of central water purification plants compared to that of the individual reverse osmosis systems used with HHD machines. The use of heat exchangers to reduce building energy use emissions will be described in Chapter 6. The use of solar power to run dialysis machines and water purification systems is now being piloted [Agar JW, 2010]. Further technological advances are required.

This study suggests that the newer haemodialysis technologies may offer a solution. The provision of 3 hour treatments on 5.5 days a week using the NxStage equipment has a carbon footprint of just 1.9 tonnes CO_2eq per patient per year – less than half of that of thrice weekly ICHD. Meanwhile, six nightly nocturnal HHD using the NxStage equipment results in just 2.1 tonnes CO_2eq per patient per year – less than one third of the emissions of a comparable HHD regime using a standard haemodialysis machine. However, although one study, including only 32 patients and run over only a few weeks, has suggested that NxStage equipment may provide safe and effective daily short HHD [Krauss et al., 2007], more robust clinical outcomes data for these treatments are not yet available. The ongoing FREEDOM study will begin to address this uncertainty by prospectively comparing NxStage patient experiences to a matched cohort undergoing thrice weekly ICHD, with the primary endpoint being the number of all-cause hospital admissions [Jaber BL et al., 2009]. Meanwhile, in the light of the findings, research to determine the carbon footprints of the provision of haemodialysis using the other forthcoming mobile haemodialysis technologies should be undertaken.

Finally, this study was primarily designed to compare the GHG emissions attributable to those regimes commonly in use in clinical practice with standard and NxStage haemodialysis machines (Table 20). However, the emissions attributable to the provision of a consistent regime (thrice-weekly, four-hour haemodialysis treatments) using standard and NxStage haemodialysis machines are also of interest (Table 22). Although the use of NxStage equipment again results in lower emissions, it should be noted that this regime would rarely be considered to provide a dialysis dose equivalent to that realised using a similar regime using a standard haemodialysis machine.

Uncertainty in the Results

As was discussed in Chapter 4, the nature of carbon footprinting, in which every input has some degree of uncertainty associated with the assumptions and estimations relating to it, means that every carbon footprint has some degree of variation inherent within it. As the extent of this uncertainty increases, the confidence with which the carbon footprint can be interpreted diminishes.

This was a process based study and uncertainty therefore exists as a result of possible truncation errors. As an input-output approach cannot be applied to this study, the extent of any such error is not readily quantifiable.

Uncertainty arises from changes within the product or service being assessed. As such, it may not easily be identified or quantified, can sometimes be ameliorated through adequate sampling, and is accounted for in the understanding that a carbon footprint is a representative rather than exact value.

Technical uncertainty results from flawed calculations (for example, as a result of incorrect assumptions or poor quality data) and may amenable to analysis. A comparison of the results of this study with those of the study reported in Chapter 2 suggests that the calculations undertaken in this study are sound. When the emissions attributable to aspects of the further care of these patients, such as their medications, are also taken into account, the magnitude of the results of this study are commensurate with the indicative carbon burden previously attributed to the provision of all forms of dialysis (peritoneal dialysis as well as haemodialysis) that has been derived from data collated at the level of an individual renal service.

Limitations

The source of activity data for patient travel was intended to provide the most accurate model of the travel emissions of a patient undertaking ICHD in the United Kingdom [Health and Social Care Information Centre, 2010]. However, significant differences might exist between regions or internationally. Similarly, the electricity emission factors used in this study are based on the United Kingdom grid average mix of different types of generation, and the contribution of energy consumption to the emissions of haemodialysis treatments may therefore vary internationally [DEFRA, 2009].

The recognition that patients using NxStage equipment have the facility to travel was considered important in the light of the influence of such travel upon the consumables and electricity used. Although the need to make assumptions regarding the frequency of such travel, which might vary considerably between individual patients, might be perceived as a limitation, it appears to have a minimal effect on the overall results, as a patient undertaking no travel uses slightly more electricity (in powering the PAK to produce dialysate at home), but the resulting saving in GHG emissions is balanced by a rise in emissions attributable to consumables. The emissions attributable to a patient undertaking 5.5x weekly dialysis but never travelling (1,841 kg CO_2eq) are almost identical to those of a patient undertaking 5.5x weekly dialysis and travelling in line with the assumptions made in this study (1,844 kg CO_2eq).

Although those emissions attributable to the creation and revision of access surgery have been included, it has not been possible to include emissions arising as a result of the potential complications of the provision of haemodialysis (such as hospitalisations resulting from line infections, for example).

The extent to which the exclusion from this study of the emissions attributable to the production of haemodialysis machines may be seen as a limitation has been discussed with the Methods section of this chapter.

Conclusions & Recommendations

The provision of haemodialysis has a considerable carbon footprint. Although this is a function of both the treatment frequency and duration, the influence of the former is the greater. The anticipated rise in the prevalence of HHD patients, who are able to dialyse more frequently and for longer than ICHD patients, will disproportionately increase the emissions associated with the provision of haemodialysis programmes. The incorporation of emerging technologies, such as NxStage equipment, into haemodialysis programmes might offer a possible solution to this problem, and the carbon footprints of forthcoming technologies should be evaluated. Studies to determine the emissions attributable to the production of the differing types of haemodialysis machine are also required. However, research into opportunities to reduce the emissions at the level of individual treatments is also required. The extent of the reductions achievable through dialyser reuse suggest that the wider environmental and health implications of this practice merit further evaluation.

Chapter 6.

Case Studies from Renal Services in the United Kingdom.

Introduction

The preceding chapters have explored the extent of the environmental impact associated with the delivery of renal healthcare. Although a number of opportunities to reduce this impact have been outlined within these chapters, these opportunities have not been described in detail. In this chapter, four such opportunities are reported in greater depth and presented as case studies of good environmental practice within renal healthcare. The examples have been chosen to highlight how measures to reduce the environmental impact of renal healthcare may also facilitate improvements in the quality of patient care and reductions in the financial costs of delivering of this care. The barriers that might be encountered by renal services wishing to implement these initiatives are also considered.

The First Case Study. Heat Exchangers and Haemodialysis Machines.

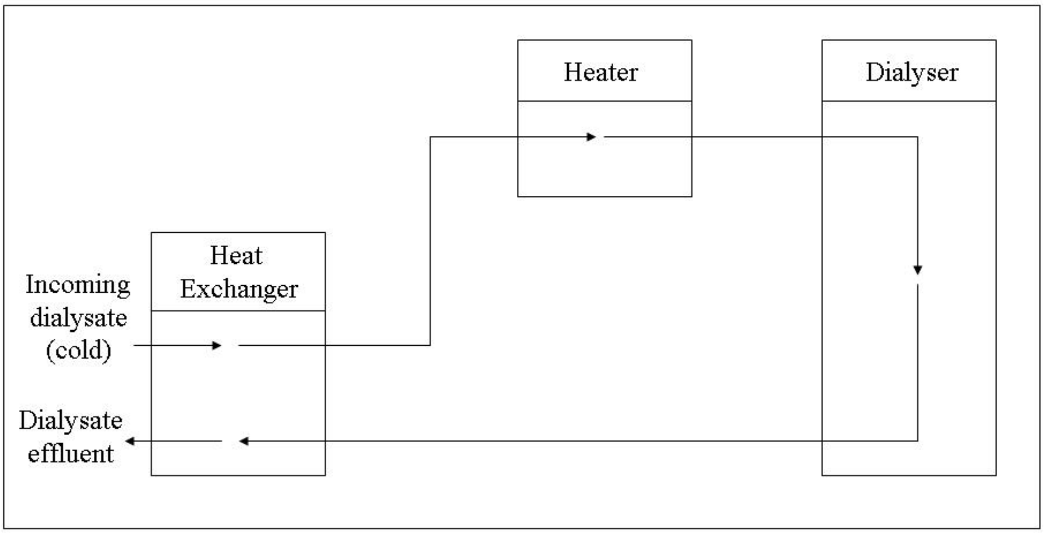
The study reported in Chapter 5 identified that the electricity consumed in the provision of haemodialysis treatments was responsible for almost 21% of the GHG emissions attributable to the treatment of a patient undertaking thrice-weekly, in-centre treatments of four hours each.

The Role of Heat Exchangers in Haemodialysis

During haemodialysis, blood is removed from the patient and pumped through a dialyser before being returned to the patient. Inside the dialyser, the blood is exposed to a dialysate (a blend of treated water and chemicals at physiological levels) across a semi-permeable membrane. Pores in the membrane allow many of the waste products of metabolism to diffuse down their concentration gradients into the dialysate. However, if the dialysate is too cool, the blood may be unintentionally cooled and the patient may become uncomfortably cold. Cool dialysate also reduces the rate of diffusion, rendering the dialysis treatment less efficient. For these reasons, the dialysate is commonly warmed to just below body temperature. In the majority of standard haemodialysis machines, a thermostat determines the demand for heat by comparing the required dialysate temperature (a preset variable) with the measured temperature, and activates the heater accordingly.

Standard haemodialysis machines may also have a heat exchanger incorporated into the system before this heater (Figure 10). The heat exchanger recaptures energy, in the form of heat, from the dialysis effluent ('used' dialysate) and transfers it to the incoming, cold, dialysate, before it reaches the heater. This pre-warming reduces the energy consumed by the heater and reduces the environmental impact of a haemodialysis treatment.

Figure 10. The role of a heat exchanger in haemodialysis.



A Case Study to Illustrate the Use of Heat Exchangers

The Kent and Canterbury renal service has predominantly purchased Braun Dialog+ haemodialysis machines, and these have been supplied without heat exchangers. However, the purchase of a number of haemodiafiltration machines (which are similar to haemodialysis machines but utilise higher hydrostatic pressures across the semi-permeable membrane to achieve additional solute clearance by convection) with built-in heat exchangers highlighted the potential financial and environmental savings that heat exchangers can offer. The following study was therefore designed to evaluate the potential financial and environmental savings attributable to the fitting of heat recovery devices to Braun Dialog+ dialysis machines.

Methods

Five standard haemodialysis machines (Dialogs 1 to 5) and one haemodiafiltration machine (HDF) (with pre-fitted heat exchanger) were selected at random from those in regular use at the Maidstone dialysis unit. Simulated four hour treatments were undertaken on each machine before and after the fitting of the heat exchanger device. A number of measurements were taken on each run.

The ambient room temperature was recorded to ensure consistency in the test environment, as variations in the room temperature might be anticipated to influence heater demand. For a similar reason, the inlet temperature (the temperature of the water immediately prior to entering the dialysis machine) was also recorded. This water has been stored in tanks, filtered, purified in the reverse osmosis plant, and distributed around the dialysis unit to the station at which the machine is positioned. The temperature of the water will therefore have increased since its arrival from the local water supplier, but the extent of this increase will vary both seasonally and with demand. The electrical energy consumed during the treatment was measured directly using an energy monitor fitted between the wall socket and the machine plug. The treatment cost was calculated using an electricity rate of £0.089 per kWh.

The average heater output was also determined. This represents the demand for heat required by the machine. It is expressed as a percentage, with 100% indicating maximal heater output. An average for each simulated treatment was obtained by recording the heater output at regular intervals. It was hypothesised that the addition of a heat exchanger would be reflected in reductions of the average heater output and the energy consumed per treatment.

Results

The results of the study are shown in Table 23.

Table 23. The electrical energy consumed during simulated haemodialysis treatments using different machines before and after the addition of a heat exchanger.

Machine Type & Number	Before & After Heat Exchanger	Ambient Temp (ºC)	Inlet Temp (ºC)	Average Heater Output (%)	Energy Consumed Per Treatment (kWh)	Energy Saving Per Treatment (kWh)	Energy Saving expressed as a percentage of Energy Consumed	Treatment Cost (£)
Dialog 1	**Before**	21	18.7	47	4.94	1.02	20.6	0.44
	After	21	18.7	37	3.92			0.35
Dialog 2	**Before**	21	18.7	45	4.71	0.66	14.0	0.42
	After	21	18.7	36	4.05			0.36
Dialog 3	**Before**	22	19.2	44	4.84	1.06	21.9	0.43
	After	21	18.2	33	3.78			0.34
Dialog 4	**Before**	22	19.2	44	4.58	0.90	19.7	0.41
	After	21	18.2	35	3.68			0.33
Dialog 5	**Before**	22	20.2	44	4.76	0.68	14.3	0.42
	After	22	19.2	37	4.08			0.36
HDF [a]	**Before**	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	After	22	19.2	35	3.70			0.33
Average						0.86	18.1	

[a] The results obtained using the haemodiafiltration machine are included for reference.

Discussion

Local and National Reductions in Greenhouse Gas Production

The average reduction in the energy required for each treatment was 0.86 kWh, representing an 18.1% increase in efficiency. Assuming that each machine is used twice daily for four hours, six days a week for 52 weeks of the year, an annual energy saving of 536.64 kWh per machine (2 * 6 * 52 * 0.86) is predicted. Applying a conversion factor of 0.50748 kg CO_2eq per kWh [DEFRA, 2009], this in turn equates to an annual saving of 272.33 kg (0.272 tonnes) of CO_2eq per machine per year. For the 83 machines in use across the Kent and Canterbury renal service, this equates to an annual energy saving of 44,541 kWh and an annual reduction in GHG production of 22.6 tonnes of CO_2eq.

The environmental benefits of installing heat exchangers can be placed into context by approximating their impact upon the carbon footprint of the Dorset Renal Service, which was determined in Chapter 4. The Dorset Renal Service provides regular haemodialysis treatments to 227 patients (including two home haemodialysis patients) using dialysis machines from a number of manufacturers. The vast majority of these machines, if not all, are fitted with heat exchangers. If it is assumed that, firstly, these 227 patients all receive thrice-weekly, four-hour treatments and that, secondly, the service uses only Braun Dialog+ machines fitted with heat exchangers, then the energy saving resulting from the heat exchangers is (227 * 3 * 52 * 0.86) 30,454 kWh per year. Applying a conversion factor of 0.50748 kg CO_2eq per kWh [DEFRA, 2009], this in turn equates to an annual saving of 15,455 kg (15.5 tonnes) of CO_2eq per year. Were heat exchangers not used, the carbon footprint of the Dorset Renal Service would therefore rise from 3,006 tonnes to 3,021 tonnes, an increase of 0.5%.

There are approximately 1,150 Braun Dialog+ machines in operation in the United Kingdom at present (correspondence with Ian Smyth, BBraun Avitum, United Kingdom, by email, December 16th, 2009). If each of these were to be fitted with a heat exchanger, and assuming once again that each machine is used twice daily, six days a week for 52 weeks of the year, an annual saving of 313 tonnes CO_2eq would be realised.

Although PAS2050 suggests that the emissions associated with the manufacture of machinery that is used repeatedly during a process are not included in the assessment of the emissions attributable to that process [British Standards, DEFRA, Carbon Trust, 2008], it is acknowledged that the manufacture of heat exchangers would incur a carbon cost in itself. However, this is estimated to amount to less than one percent of the carbon savings derived from the improved energy efficiency in the first year of use alone.

Financial Costs and an Investment Appraisal

Assuming an electricity rate of £0.089 per kWh, the lower energy usage translates to financial savings of £0.077 per treatment (0.089 * 0.86), and an annual financial saving of £48.05 per machine (if used twice daily, six days a week, for 52 weeks of the year). The unit cost of a heat exchanger device for a Braun Dialog+ dialysis machine (£189) could be recouped within four years (£189/£48.05) and a saving made thereafter.

Fitting heat exchangers to the 83 dialysis machines in the Kent and Canterbury renal service would require an initial investment of £15,687, with an annual saving of £3988.15 (£48.05 * 83) being made once this had been recouped at four years (with the expected working lifespan of these machines being up to 10 years or 25,000 hours of dialysis).

The Second Case Study. The Salvage of Reject Water in a Haemodialysis Unit.

The preceding chapters have shown that the GHG emissions attributable to the water use for haemodialysis amount to 0.2% of the emissions of a typical renal service and 0.4% of the emissions of a four hour, in-centre treatment using a standard haemodialysis machine. The impact of water use upon the carbon footprint of renal healthcare is therefore small in comparison to that of many of the other resources used. However, the volume of water consumed by standard haemodialysis machines remains a striking feature of the treatment, and the environmental arguments for water conservation are based predominantly around preventing the depletion of natural resources rather than reducing emissions. Indeed, the same water stores that were available to the 300 million human beings inhabiting the earth during Roman times are now shared amongst a global population of 6.7 billion people, more than one third of whom now live in water-stressed countries [Food and Agriculture Organization of the United Nations, 2007]. There is therefore a need to use water wisely, yet it was established in Chapter 3 that the simple water-saving methodology reported in this case study is presently in place in only two of the 58 surveyed renal services in the United Kingdom.

Water Use and Haemodialysis

When haemodialysis is undertaken using standard machines, water is required to produce the dialysate, undertake pre-dialysis priming and post-dialysis rinsing, and to re-process the dialysis membranes. A patient with a target dialysate flow rate of 500 millilitres per minute, undergoing a four hour (240 minute) dialysis session, will require 120 litres of dialysate, which in itself requires the production of high grade water from mains water. Approximately 400 litres of mains water will be required to produce the required volume of high grade water (although this will vary depending on the efficiency of the reverse osmosis system employed). Inclusion of priming and rinsing volumes boosts this requirement to a figure approaching 500 litres of mains water per patient per dialysis session.

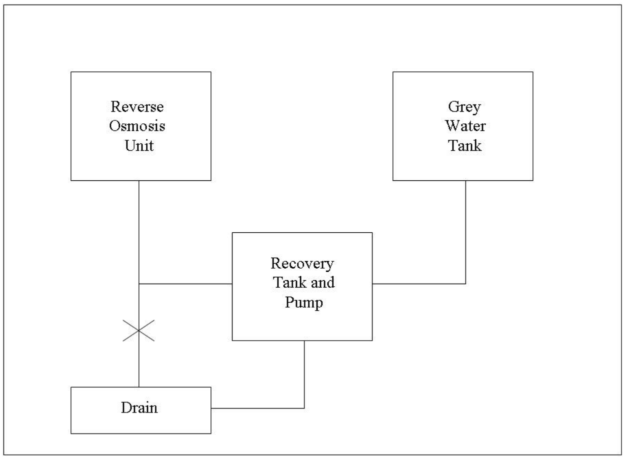
High grade water is produced from mains water by a multi-stage process starting with the passage of mains water through sand micro-filters to extract particulate matter. It is then passed over activated carbon to adsorb chlorine and organic contaminants. Calcium, magnesium, iron and manganese may be removed by ion exchange for sodium cations to soften the water. This water is then processed by reverse osmosis to remove residual salts, during which approximately two thirds of the water presented to the reverse osmosis system is rejected. The volume of this 'reject water' arising from the production of a given volume of dialysate varies with differing reverse osmosis systems. However, for the patient described above, dialysing thrice weekly for four hours, this commonly amounts to over 250 litres of water per session. The term 'reject water' is somewhat misleading; although this high-grade water is not legally acceptable for drinking, it commonly meets potable water criteria [Agar JWM et al., 2009]. It does not at any stage come into contact with the patient and therefore poses no infection risk. Yet in all but two renal services in the United Kingdom (and in the majority of services worldwide), these large volumes of good quality reject water are presently lost-to-drain. Simple methodology exists to capture reject water, which can then be recycled for alternative uses such as irrigation, laundry, sanitation or low-pressure boiler feed.

Case Studies to Illustrate Methodology

In 1997, two new reverse osmosis units were installed to supply an existing dialysis unit in Canterbury (Kent, United Kingdom). In order to achieve back up and redundancy within the system, these were installed in parallel. The suspicion that the volumes of reject water being visibly lost-to-drain from this system were substantial was confirmed through the use of simple flow meters, prompting consideration of its salvage. With the support of the hospital's Estates department, a system to recover this water at a rate of 800 litres per hour was implemented by 1999 at a cost of £15,000.

The system is extremely simple (Figure 11). It was installed under a 'small works' policy and has been running satisfactorily for ten years. It should be appreciated that pressure cannot be applied directly to the 'output-to-drain' of a reverse osmosis system; reject water must be allowed to flow freely away to the tank, and subsequently onwards to the drain if it is genuinely surplus. In the system described here, where the distance between the reverse osmosis unit and the water tank necessitates a pump, the solution is to allow the salvaged reject water to flow initially to a recovery tank in the basement, before it is pumped up to a second water tank on the roof. In other systems where a pump is not required, the reject water might simply be allowed to flow from the reverse osmosis to a single water tank. In the system reported here, the second water tank supplies the toilets, with 7 litres of water used for each toilet flush.

Figure 11. A schematic representation of the water salvage system in place at the Canterbury haemodialysis unit.



The system is controlled by float switches. Should the second water tank become full (for example, during the twilight dialysis session when fewer toilets are being flushed), the float switches divert the reject water to flow to drain, thereby preventing the recovery pump from running unnecessarily in the absence of demand for water. This plant required chemical disinfection on a monthly basis. Diverter valves were therefore employed to direct water (and chemicals) draining from the reverse osmosis system to the drain after each disinfection.

When the dialysis unit was redeveloped and expanded in 2007, the new plant was connected into the reject water recovery system. However, the configuration of the reverse osmosis system was amended from parallel to series, with each individual reverse osmosis system remaining capable of supporting the dialysis unit independently. Whilst the reject water from the first reverse osmosis system is salvaged as it flows to drain, the reject water from the second is recycled back into the first reverse osmosis system. In this way, the new configuration is both larger and more efficient. The realisation of the system's potential to salvage up to 1,300 litres of reject water per hour is dependent upon it running at full capacity (45 points of use) and the degree of redundancy (80%) built in. In the new plant, the chemical disinfection is required on an annual rather than monthly basis. A simple 'recycle' valve allows the water from the reverse osmosis system to be lost-to-drain at such times.

Similar water conservation techniques were incorporated into the design brief of a new-build satellite dialysis unit situated in nearby Ashford (Kent, United Kingdom). Once again, the two reverse osmosis systems lie in series, with reject water from the second revere osmosis system being recycled into the first. The system overall has the potential to salvage up to 960 litres of reject water per hour from the first reverse osmosis system. The Ashford dialysis unit runs for 15 hours per day, for 312 days per year. A potential volume of 14,400 litres of reject water is salvaged each day, equating to 4,492,000 litres per year. This is used in its entirety in the local laundry room, where it contributes 10% of the overall water use (3,700,000 litres per month). An added environmental and financial benefit is that the softened water allows the use of less detergent.

Discussion

Financial Savings from Salvaging Reject Water

Current regional water rates are £1.35/1,000 litres during peak hours and £0.75/1,000 litres during off-peak hours. The average cost of mains water to the dialysis unit, given its operating hours, is £1.00/1,000 litres. Waste water is charged at £1.69/1,000 litres for 80% of the volume used. The total cost of water and waste is therefore £2.35/1,000 litres (£1 from water, and 0.8 x 1.69 from waste). The potential 4,492,000 litres of water conserved annually represents a saving of £10,558.

The salvage pump has a flow rate of 2,400 litres per hour and therefore runs for 6 hours per day. Energy consumption is 0.68 kWh. Daily energy use is therefore 3 kW, and yearly energy use is 936 kW (312 x 3). Regional electricity rates are £0.06 per kWh. The cost of the electricity to run the salvage pump is therefore just (0.06 x 0.68 x 6 x 312) £76.38 per year. The overall potential annual saving is therefore £10,481.62.

The cost of integrating the water conserving methodology into the new build was £2,500 (tank and control panel £1,300; piping £1,200; the piping was laid alongside other services required by the new build, so no additional cost was incurred for groundwork).

Reductions in GHG Emissions from Salvaging Reject Water

As has been mentioned previously, the environmental arguments for water conservation are based predominantly around preventing the depletion of natural resources rather than reducing GHG emissions. Water stress varies geographically and is, for example, of greater concern in southern and Eastern England than elsewhere in the United Kingdom. A water footprint, rather than a carbon footprint, would therefore provide a stronger environmental argument in favour of the methodologies advocated here. However, in simple terms and using an emissions factor of 0.276 g CO_2eq per litre of mains water [DEFRA, 2009], the reduction in GHG emissions derived from the use of 14,400 litres of reject water in place of mains water per day, at the Ashford unit described above, is 3.974 kg CO_2eq per day or 1239.88 kg CO_2eq per year (1.24 tonnes).

Using an emissions factor of 0.50748 kg CO_2eq per kWh [DEFRA, 2009], the GHG emissions attributable to the electricity required to operate the salvage pump is 475.00 (0.5 kWh x 0.50748 x 6 x 312) kg CO_2eq per year. Therefore the overall reduction in GHG emissions attributable to the implementation of this methodology in the single renal unit is (1239.88 – 475) 764.88 kg CO_2eq per year (0.76 tonnes).

Assessing Opportunities to Implement Reject Water-Conservation Methodology

Three opportunities exist to implement reject water conserving methodology. The optimal scenario is to integrate the methodology into the design of a ‘new build’ dialysis unit. In such circumstances, a wider range of possible uses for the reject water may be considered, and particular consideration should be given to the possibility of locating facilities which might be anticipated to benefit from the reject water (for example, the laundry services) in close proximity to the new dialysis unit. Pumping water for longer distances or against gravity will incur potentially unnecessary energy costs upon the new system.

The second opportunity is during the replacement of existing reverse osmosis systems which may have become outdated or unreliable. It should be remembered that, as mentioned earlier, more modern reverse osmosis systems are likely to be more efficient and reject less water to drain (therefore reducing the potential for reject water salvage).

The third opportunity is simply to retro-fit the reject water conserving methodology to existing reverse osmosis systems. In both the second and third scenarios, the range of practical (i.e. money saving) uses for the reject water may be more limited, as the costs of delivering the water to the required site may be greater.

It should be acknowledged that the implementation of reject water conservation methodology may not be possible in all renal units. A number of barriers may be encountered. These may include the practical and financial considerations involved in laying the pipe-work required to transfer the conserved reject water to the site at which it will be re-used. Secondly, not all renal units will have the space required to house the water storage tank. Thirdly, as was illustrated in the description of the Canterbury unit, the existing layout of the renal unit may create the need for a further water tank (as water cannot be pumped directly out of a reverse osmosis system but must be allowed to drain freely at the rate at which it is produced) and this will also require further space. For reasons such as these, it is essential for members of a renal service evaluating the possibility of water salvage to gain the support of the local Hospital Estates department.

It is also important to ensure that the use to which the reject water is put is supported by a back-up mains supply to cover any interruptions (for example during maintenance or disinfection of the dialysis unit).

Factors Influencing the Potential Volume of Reject Water that can be Salvaged from a Dialysis Unit

A number of factors influence the potential volume of reject water that can be salvaged from a dialysis unit. The most important determinant is simply the amount of water that the reverse osmosis system processes. The higher this value, the greater the volume of reject water that will be produced, and the greater the potential for reject water salvage. The amount of water processed will be dependent upon variables specific to the individual dialysis unit, including the opening hours, the number of dialysis stations (or 'points of use'), and the capacity at which the unit is run (determined by the number of patients and the length of their sessions). A second factor is the design of the plant; twin stream systems with reverse osmosis units in parallel typically produce greater volumes of reject water than single stream systems. A third factor is the type of plant installed. More modern reverse osmosis systems are generally more efficient and reject less water to drain. A fourth factor is the degree of redundancy built into the system to accommodate periods of breakdown, service and repair with the reverse osmosis systems.

Whilst there is no size below which a dialysis unit becomes too small to make reject water salvage practical, the financial benefits from recycling the salvaged reject water must be considered against the costs of implementing the methodology, and the 'breakeven point' may be further in the future for smaller units.

Opportunities for the Re-use of Reject Water

Reject water is high grade water. Although it commonly meets potable water criteria [Agar JWM et al., 2009], it is not legally acceptable for drinking and the precise quality of the reject water produced will vary from region to region. Possibilities for its re-use within renal units and hospitals include the local sanitation systems, within laundry departments, as low-pressure boiler feed and in the production of steam in the sterilisation units. In more arid environments than the United Kingdom it has also be used to irrigate land [Agar, 2010]. Practical considerations are important when identifying the most appropriate use. For example, salvaged reject water can only be used in laundry services if the plumbing required is feasible and affordable.

Further Discussion

The published literature around this subject is very limited, despite the increasing scarcity of water worldwide, the increasing numbers of patients receiving haemodialysis globally, the huge advances in other areas of dialysis technology and the massive potential environmental and financial savings associated with haemodialysis water conservation projects. Only one group has reported a similar water conservation project to the one described here [Agar et al., 2009]. The same group has also described its use in home haemodialysis [Agar et al., 2008]. A second group has reported a desalination trial of un-segregated reject water combined with dialysis effluent for reuse in irrigation [Tarrass et al., 2008]. However, the potential for bacterial and viral contamination due to the inclusion of dialysis effluent complicates this methodology, and it seems likely that the major savings derive from the salvage of reject water – for which the technology is also less expensive to install.

Haemodialysis facilities utilise vast quantities of water and, in the majority of facilities worldwide, large volumes are unnecessarily lost-to-drain. Whilst the net environmental savings achievable through salvaging reject water from the unit described here are modest when considered in terms of the reduction in GHG emissions (0.76 tonnes CO_2eq per year), these benefits are achieved alongside a net financial saving of over £10,000 per year. Although the implementation of similar reject water salvaging methodology may not be as financially viable in every dialysis unit, all units would therefore be wise to consider such a project.

The Third Case Study. The Follow Up of Renal Transplant Recipients by Telephone Consultation: Three Years Experience from a Single Renal Unit in the United Kingdom.

Telephone consulting offers clinicians a means by which to meet the challenge of improving quality and accessibility despite rising caseloads and heightened patient expectation [Car & Sheik, 2003]. It is now utilised to triage patients, manage acute and chronic conditions, enhance compliance, and communicate results. When used appropriately, telephone consulting offers the patient and clinician multiple benefits, including enhanced access to healthcare, heightened continuity of care, reduced travelling and considerable time savings.

Although the potential for reducing the environmental impact of healthcare through tele-health initiatives has previously been considered [Smith et al., 2007; Massino et al., 2010], there have been very few studies to date that have quantified the potential benefits in terms of reductions in GHG production [Wootton et al., 2010].

Guidelines for nephrologists in the United Kingdom do not suggest a frequency with which stable renal transplant recipients should be followed up although most services offer three to six monthly appointments. This is in keeping with the guidance of the American Society of Transplantation, which notes that there are virtually no scientific data on which to base decisions regarding the optimal frequency (or type) of follow up of these patients [Kasiske et al. 2000]. This case study describes the use of telephone consulting to provide three monthly follow up to renal transplant recipients in a single renal unit over a three and a half year period.

Case Study

The University Hospital of Coventry and Warwickshire (UHCW) renal service began to offer telephone consultations to provide routine follow up to renal transplant recipients in 2006. The service now provides approximately 350 appointments per year, facilitating follow up to 123 of the 360 patients in whom transplantation was undertaken more than one year previously.

The service is offered to patients at their physician's discretion. Most patients are well known to the department and all must have demonstrated stable graft function. Patients receive quarterly clinic appointments, of which one remains a face-to-face consultation. Consultations commence with the patient ringing through to the clinician at a time detailed in their appointment letter, which also requests that they provide their weight and blood pressure readings. As with face-to-face consultations, blood tests are undertaken beforehand; patients may attend their family practice, the city centre phlebotomy service, or their local hospitals. Fifteen minutes are allocated per consultation. Clinic letters are copied to the patient, along with any necessary prescriptions, a blood test form and their next appointment details. The annual face-to-face consultation allows for physical examination (including urinalysis).

The results of the survey reported in Chapter 3 indicate that this is the only service of its nature in the United Kingdom. Informal feedback from patients to clinicians suggests high levels of satisfaction. To date, only two patients have opted to return to face-to-face follow up. There have been no reported patient safety issues.

Discussion

Telephone consulting has mainly been used to manage the demand for care, predominantly out-of-hours and within the emergency department and primary care settings (where more than half of out-of-hours calls can be handled by telephone advice alone) [Christensen et al, 1998; Bunn et al., 2004]. Telephone consulting in other services is less well researched.

A literature search undertaken on February 17th, 2011, through Pubmed for articles published in English since 1st January 2000 using the search term (("telemedicine" OR "tele-health") AND "transplant") returned no reports of telephone-based care for renal transplant recipients, although telemedicine for dialysis patients has been described [Whitten & Buis, 2008; Mitchell et al., 1996;

Rumpsfield et al., 2005]. Videoconferencing can facilitate routine consultations between nephrologists and dialysing patients [Whitten & Buis, 2008]. Telemedicine offers haemodialysis and peritoneal dialysis patients improved access, reduced costs and travel savings [Jennett et al., 2003].

The few studies assessing patients' and clinicians' perceptions of telephone clinics are limited to primary care. In one study, both groups considered telephone consultations to be convenient, and to be best suited to the management of chronic conditions [McKinstry et al., 2009]. In another study, patients with chronic diseases managed by telephone care changed their perceptions such that, at end of the two year study, they believed that telephone consultations could be used to manage their conditions [Wasson et al., 1992].

The Benefits of Telephone Consulting

In Chapter 2 it was noted that high quality healthcare should be safe, timely, effective, efficient, equitable, and patient-centred [Institute of Medicine, 2001], but also that it has been argued that sustainability should lie at the heart of health service decision-making [Royal College of Physicians, 2010(a)]. Whilst the model of care reported here delivers in each of these domains, it offers particular improvements in efficiency, patient-centred care and sustainability. Those aspects of quality within healthcare that are of most relevance to telephone consulting are now discussed, with reference to existing literature.

Patient-centred, convenient care

Many transplanted patients have previously attended the hospital (for example, for haemodialysis treatments) with a very high frequency for many years. The experience of the clinicians at the UHCW is that these patients perceive a positive health gain from telephone consultations. Whilst this may simply reflect the improved convenience, it is also possible that this health gain is attributable to heightened patient empowerment resulting from the telephone clinic model; although the relative reduction in annual face-to-face appointments is considerable (from four to one), it represents only a small absolute reduction in the number of annual face-to-face appointments (just three appointments).

Patient empowerment is a key component to the successful management of chronic disease [Bodenheimer, 2002]. More research to determine the nature of this under-recognised benefit of telephone consulting is required. The use of RenalPatientView, an existing patient empowerment tool [Turner, 2006], would compliment the use of telephone consultations.

In the UHCW model, the patients ring in to the clinic at an allocated time, thereby negating the need to advise where they will be in advance, and allowing them to ring, for example, from the workplace more conveniently. It is likely that the financial cost of their call is usually more than offset by savings in fuel costs and parking.

Safe Care

Clinicians familiar with face-to-face consultations may question the safety of telephone consultations and this is indeed an area in which robust evidence is presently lacking. Whilst a review of telephone-related malpractice suits determined that patient safety is compromised mainly when consultations include diagnostic or triaging components [Katz et al., 2008], there is evidence that their use in the provision of routine follow up is safe [Wasson et al., 1992]. A systematic review of the literature found no increase in adverse effects or use of other services [Bunn et al., 2005].

The care of patients receiving immunosuppression should encompass vigilance for skin lesions, and patients followed by telephone consultation should receive regular education around this. In the UHCW service, those patients that report lesions and who do not already have open access to the dermatology service are advised to seek an urgent dermatology referral through their General Practitioner under the 'two-week wait' system.

One randomised controlled trial, involving 497 patients with chronic diseases being managed in primary care, is of particular note [Wasson et al., 1992]. Follow up in a traditional clinic was compared against follow up in which the recommended interval for face-to-face follow up was doubled and three intervening telephone consultations were arranged. Telephone-care reduced utilisation of medical services without adversely affecting patient-reported health. Telephone-care patients had fewer scheduled and unscheduled clinic visits than usual-care patients, and fewer and shorter hospital admissions. The estimated expenditure of their care was 28% less in the telephone-care group. When new or worsening problems were uncovered during a telephone consultation, the patient was seen at the clinic or admitted to hospital in a timely fashion. The patients' diagnoses and demographics, and the degree of continuity of care, were similar across the two groups. This study therefore suggests that the increased communication afforded by more frequent contact may be the determinant of the underlying health benefits of telephone care.

Sustainable Care

Chapter 4 described the extent to which patient travel contributes to the carbon footprint of a renal service. As the potential reductions in GHG emissions attributable to telephone consulting have not previously been studied, the reduction in emissions associated with the UHCW telephone clinic model are outlined here.

Data was collected from 30 patients attending two consecutive telephone clinics. It was assumed that, had patients attended a face-to-face clinic, they would have travelled from, and returned to, their homes. Each patient's return journey length was calculated from their postcode using GoogleMaps (http://maps.google.co.uk). Had these 30 patients attended clinic, they would have travelled a total of 1,180.10 km (mean 39.34 km, range 1.76 – 241.26 km), with only 64.74 km (5.8%) undertaken by public transport (Table 24). The GHG emissions arising from each patient's travel were calculated using DEFRA conversion factors specific to the transport modality that they would use to attend their local clinic [DEFRA, 2009]. A mean value of 8.05 kg CO_2eq was identified[‡].

Of course, the provision of a telephone clinic also generates GHG emissions. The use of a mobile telephone for one minute has been reported to generate 0.057 kg CO_2eq [Berners-Lee, 2010]. If the average duration of the phone call required for a single consultation is estimated to be eight minutes, and if it is assumed that patients will ring in to the clinic on mobile telephones (rather than landlines),

[‡] The indicative carbon burden of a single outpatient appointment in the Dorset Renal Service was calculated in Chapter 4. Further analysis of the data presented in Table 12 indicates that patient travel was responsible for 9.9 kg CO_2eq of the 22 kg CO_2eq attributed to an individual appointment – a figure comparable to the value of 8.05 kg CO_2eq determined in this case study. Accepting that geographical and demographical differences exist between the populations served by Dorset Renal Service and the UHCW Renal Service, it would appear that the use of a telephone clinic service reduces the GHG emissions of a single consultation by approximately one third.

then the GHG emissions attributable to the telephone call will be 0.456 kg CO_2eq. The remainder of the components of the telephone clinic are similar to those of a traditional face-to-face clinic. The annual 350 telephone consultations therefore result in an estimated reduction in GHG emissions of [(350 * 8.05) – (350 * 0.456)] 2,658 kg CO_2eq.

Table 24. Data collected from two consecutive telephone consultation clinics.

Patient	Choice of Transport Modality	Return distance from patient's home to their local renal clinic (km)	DEFRA Conversion Factor [DEFRA, 2009]	GHG Emissions (kg CO_2eq)
1	Bus	14.08	0.10462	1.47
2	Bus	6.14	0.10462	0.64
3	Bus	13.34	0.10462	1.40
4	Bus	16.34	0.10462	1.71
5	Bus	4.56	0.10462	0.48
6	Bus	10.28	0.10462	1.08
7	Diesel, Large (over 2.0L)	35.74	0.25762	9.21
8	Diesel, Large (over 2.0L)	7.04	0.25762	1.81
9	Diesel, Medium (1.7 - 2.0L)	4.38	0.18939	0.83
10	Diesel, Medium (1.7 - 2.0L)	98.6	0.18939	18.67
11	Diesel, Medium (1.7 - 2.0L)	4.48	0.18939	0.85
12	Diesel, Small (up to 1.7L)	12	0.15277	1.83
13	Diesel, Small (up to 1.7L)	36.94	0.15728	5.81
14	Petrol, Large (over 2.0L)	163.74	0.29762	48.73
15	Petrol, Medium (1.4 to 2.0L)	34.2	0.21493	7.35
16	Petrol, Medium (1.4 to 2.0L)	110.36	0.21493	23.72
17	Petrol, Medium (1.4 to 2.0L)	35.5	0.21493	7.63
18	Petrol, Medium (1.4 to 2.0L)	19.84	0.21493	4.26
19	Petrol, Medium (1.4 to 2.0L)	38.74	0.21493	8.33
20	Petrol, Medium (1.4 to 2.0L)	17.98	0.21493	3.86
21	Petrol, Medium (1.4 to 2.0L)	22.4	0.21493	4.81
22	Petrol, Medium (1.4 to 2.0L)	22.7	0.21493	4.88
23	Petrol, Medium (1.4 to 2.0L)	1.76	0.21493	0.38
24	Petrol, Small (up to 1.4L)	8.84	0.18200	1.61
25	Petrol, Small (up to 1.4L)	113.92	0.18200	20.73
26	Petrol, Small (up to 1.4L)	18.68	0.18200	3.40
27	Petrol, Small (up to 1.4L)	43.5	0.18200	7.92
28	Petrol, Small (up to 1.4L)	12.98	0.18200	2.36
29	Petrol, Small (up to 1.4L)	241.26	0.18200	43.91
30	Petrol, Small (up to 1.4L)	9.84	0.18200	1.79
	Total **Mean**	**1180.16** **39.34**		**241.47** **8.05**

Although the majority (25) of the 30 patients reported a return travel distance of less than 50 km, there was considerable variation in the extremes of distance reported. Renal transplantation is undertaken in tertiary referral centres which often cover large geographical areas. Whilst the follow up of patients from the peripheries of these catchment areas is often ‘handed back’ to their local renal services, it is not uncommon for some patients to travel long distances to transplant clinics (for example, patients 14, 16 and 25). Patient 29 had been under the care of the UHCW renal service for many years and therefore, after moving away from the area, had opted to continue to return to the service for follow up rather than register with a new service (a relatively rare but not exceptional scenario).

Further reductions (and time savings) result from reduced physician travel to outlying clinics as an estimated annual total of 20 clinics across two sites (Stratford and Warwick) became redundant. Assuming the physician would have undertaken return journeys from the UHCW site by car, this further annual reduction in GHG emissions amounts to ([10 x 0.20487 x 2 x 20.4] + [10 x 0.20487 x 2 x 36.2]) 232 kg CO_2eq (where 20.4 and 36.2 are the return distances to the outlying clinics, in km, and 0.20487 is the conversion factor for an average sized car [DEFRA, 2009]).

Further potential, but probably less significant, carbon savings result from the reductions in building energy use (for example, the lighting and heating requirements of a hospital waiting room) and in associated staff commuting (for example, outpatient nurses and reception staff). The overall annual carbon saving is therefore estimated to be over 3 tonnes CO_2eq.

Setting Up a Telephone Consultation Service

Potential disadvantages and barriers

Telephone consultation is not appropriate when formal physical examination is a likely necessity. Its role is primarily in the management of established chronic disease, rather than where diagnostic evaluation is required. Even during follow up, one clear drawback of telephone consulting remains the loss of visual clues to a patient’s well-being [McKinstry et al., 2009]. A thorough history is therefore important and familiarity with the patient must not be considered to be a substitute for this.

Cultural barriers, as well as logistical and administrative challenges, may present potential barriers to effective implementation of telephone services. For example, the clinician might ideally wish to control the process by which patients organise their subsequent appointment, a duty which previously would have been undertaken by the outpatient receptionist, in order to include the information in the clinic letter (the patient copy of which also acts as the appointment letter). Similarly, patients might find automatically generated reminder letters asking them to 'attend' clinics confusing; such letters should be tailored to the telephone service.

Patient Selection

The UHCW service does not currently adhere to firm criteria regarding patient selection. However, the spectrum of patients to whom the service is offered has broadened as a result of positive responses from those already entered into it and the increasing experience and confidence of the physicians. When the service is offered to patients, its optional nature – and the opportunity to return to face-to-face clinics at any stage – is emphasised. The service is only offered to patients with stable graft function (a twelve month period appears to be sufficient). Those with complex co-morbidities, or in whom regular physical examination is a likely necessity, are less likely to be suitable.

Telephone consultations are less appropriate for patients with hearing, speech or cognitive impairment, or where a language barrier exists. Patients should ideally be well known to the department and the clinician providing telephone follow up; both clinicians and patients place greater confidence in telephone consultations when a face-to-face relationship already exists [McKinstry et al., 2009]. It would seem that telephone consultations are not well suited to managing patients with poor attendance records in face-to-face clinics, as they are also likely to be poorly compliant with telephone clinics (seven such patients have been discharged back to face-to-face follow up from the UHCW service).

Funding

Acute trusts are presently rewarded for their services through the Payment by Results (PbR, see Appendix 1) system. Guidance on the application of PbR to non-face-to-face outpatient activity is provided in clauses 344-346 of the PbR Guidance for 2011/12 [Department of Health, 2011]. A face-to-face consultation in renal medicine commands a tariff of £128, whilst the tariff for all non-face-to-face activity is £23. This is derived from the average of the reference costs reported annually across all specialties. As such, it is quite possible that this figure does not reflect the true financial cost of any given non-face-to-face consultation, particularly as such activity may range from a short phone call from a single junior staff member to a video-conference with an experienced multidisciplinary team. It is therefore important to note that the tariff for non-face-to-face activity is designated as non-mandatory and can be negotiated with Primary Care Trust commissioning bodies.

Although beyond the scope of this report, a full economic analysis is therefore required, and should consider the changes to the staff workloads; for example, that of the outpatient department nursing staff is reduced, whilst that of the administration team will remain unchanged or may even increase. It might also include the implications for patients (who save on travel costs and from not taking time off work) and for Trusts (for example, the Trust may incur costs for blood tests undertaken elsewhere, whilst suffering a loss in car park revenue).

Potential National GHG Reductions

On the 31st December, 2007, there were 22,300 adults with functioning renal transplants in the United Kingdom [Byrne, Steenkamp et al., 2010). Accepting the inaccuracies resulting from geographically and demographically related differences in the distances and modalities of outpatient travel, and assuming that patients would otherwise be seen quarterly, we estimate that if the care of 30% (6690) of these patients were to be provided by telephone clinic model, an annual carbon saving of (6690 x 3 x 8.05) over 160 tonnes CO_2eq might be realised.

Wider Implications

The UHCW service currently provides follow up to seven patients with stable chronic kidney disease (CKD), a condition which is also well suited to follow up by telephone consultation. The age standardised prevalence of stage 3-5 CKD within the United Kingdom has been estimated at 8.5%, but the condition remains largely under-recognised (only 2.1% of patients with stage 3-5 CKD had a coded diagnosis of renal disease) [Stevens et al., 2007]. The proportion of patients diagnosed with CKD is anticipated to rise, due in part to the provision of national guidance [National Collaborating Centre for

Chronic Conditions, 2008]. Telephone consulting may become an important component of the service reconfiguration that would be required for current renal services to meet this increased demand.

Furthermore, as telephone consulting is well suited to the follow up of patients with stable chronic conditions, its widespread adoption across different specialties (for example, to provide follow up to patients with diabetes or heart failure) offers considerable benefits to patients and the environment.

Overall, this case study suggests that, implemented appropriately, the use of telephone consulting to follow up renal transplant recipients is safe, empowers patients, improves access to healthcare and confers environmental benefits. Further research is required to better understand the attitudes of patients to these clinic models and to validate their safety.

The Fourth Case Study: Sustainable Waste Management Strategies.

The disposal of waste contributes to the environmental impact of healthcare. Renal healthcare, and dialysis in particular, produces large amounts of plastic and packaging waste. Chapters 4 and 5 have reported the contribution of waste management to the GHG emissions of a renal service and haemodialysis treatments respectively. This case study describes how the fundamental principles of waste reduction, 'reduce - reuse - recycle', can be applied within a dialysis unit to realise both financial and environmental savings.

The scale of waste in the NHS

The NHS generates over 400,000 tonnes of waste per year, of which almost one third is clinical waste [Hutchins & White, 2009]. This equates to 5.5 kg of waste per patient per day. Although waste management is reported to contribute only 3% of the GHG emissions of NHS England [Sustainable Development Commission, 2008], waste minimisation strategies have the potential to achieve much greater savings, by reducing the need for manufacture of medical equipment and thereby the "embedded" carbon which is attributed to procurement. Waste management is also a considerable economic burden, with an annual cost to the NHS of around £73 million. The proven opportunities for financial savings [Tudor et al., 2008] might be used as a driver for change towards more sustainable waste management strategies within renal units.

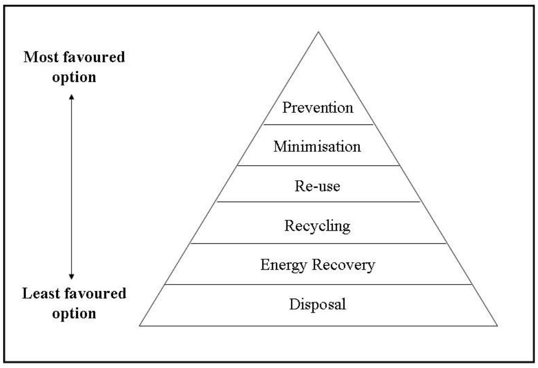
The longer term goal must be to match or exceed the achievements of other countries. In France and Germany, where a greater commitment to sustainable resource use is embedded within the nations' culture and legislation, and where the strategies used to manage infection risks perhaps exhibit a greater sympathy to the health threat presented by GHG emissions and climate change, the production of healthcare waste is markedly lower (at 1.9 kg and 0.4 kg per patient per day respectively) [Tudor et al., 2008].

As has previously been described, the increasing availability of dialysis has been dependent upon single-use, pre-packaged products. Chapters 4 and 5 have outlined the extent to which the disposal of the resultant waste contributes to the GHG emissions attributable to a haemodialysis treatment and a renal service respectively. However, it is clear from the results of the survey reported in Chapter 3 that waste management strategies are rarely optimal and significant opportunity for improvement exists.

What happens to waste produced by the provision of renal healthcare?

Environmental legislation mandates a 'cradle-to-grave' approach, such that waste producers must ensure that all waste is handled, treated and disposed of safely and with minimal harm to humans and the environment. The waste management hierarchy (Figure 12) reflects the sustainability of the differing waste management options. Waste should be disposed of as high up the hierarchy as possible. As the disposal of waste by any method will have some environmental impact, the reduction of waste is at the top of the hierarchy. Reuse is followed by recovery techniques (such as recycling), whilst incineration and landfill have poor environmental profiles.

Figure 12. The waste management hierarchy.



Renal healthcare produces two main forms of waste; non-clinical (domestic) and clinical waste. Clinical waste contains human or animal tissue, blood or bodily fluids, excretions, pharmaceuticals, swabs or dressings, syringes, or other sharp instruments [Department of Environment, 1990]. Clinical waste is commonly disposed of in yellow bags and is commonly incinerated [Department of

Environment, 1994]. Increasingly, hospitals are providing orange bags for hazardous clinical waste that must be incinerated, and 'tiger bags' for offensive (low or no infection risk) clinical waste that may be adequately treated with alternative heat treatments. Waste that has not come into contact with a patient or medicine is domestic waste, although it may be produced during clinical work (eg packaging waste from medical equipment). Most Trusts presently recycle approximately one quarter of their domestic waste. The remainder is predominantly disposed of in landfill. As was discussed in Chapter 2, further research is required to better understand the respective environmental impacts of the different disposal strategies for healthcare waste.

Reduce, Reuse, Recycle in Renal Services

The recent appreciation of the importance of the topic of sustainable waste management is reflected by its increasing coverage in health estate management journals, and the development of recycling within healthcare [Park & Jeong, 2001]. However, the results of the survey reported in Chapter 3 reveal that facilities to collect plastic and packaging waste for recycling are not present in the clinical areas of over 70% of renal services. The principles most commonly used to deliver waste reduction strategies – reduce, reuse, recycle – are applicable to renal healthcare and, more specifically, to dialysis.

Reduce

Whilst disease prevention and patient empowerment will contribute to reductions in the waste generated by renal healthcare in the longer term, it is the application of the third principle of clinical transformation – leaner system development [Connor, Mortimer et al., 2010; Mortimer, 2010] - that is likely to offer more immediate results. At its simplest, the application of lean methodology involves analysing a process to ensure that the right things are in the right place at the right time. Waste can be reduced by very simple measures, including using small aperture sharps bins (so that only the sharps waste is placed inside) and unpacking equipment as it is required (so that it is only used when necessary). Similarly, to facilitate the recycling of waste arising from haemodialysis, recycling bins must be easily accessible to the staff member as they put a patient onto dialysis.

Leaner Haemodiafiltration

Opportunities to reduce waste were identified at the Queen Margaret Hospital dialysis unit in Dunfermline, which provides around 10,764 haemodiafiltration treatments per year using Fresenius 5008 machines. Previous practice was to connect a 1 litre bag of normal saline and giving set at the start of each treatment (in case the patient became hypotensive – a relatively uncommon scenario for the majority of patients receiving maintenance dialysis), despite the fact that substitution fluid may be prepared online. Around 200mls of this saline was also used to re-infuse the patient's blood at the end of the treatment. The remaining 800mls, the plastic bag containing it, and the plastic giving set – along with the extracorporeal circuit and bicarbonate bag – were all disposed of as clinical waste. Variations upon this scenario are common to many dialysis units.

First Reduction

The use of saline and giving sets was reduced by stopping the unnecessary practice of hanging a bag for emergencies in favour of using the online facilities for emergencies and re-infusion. This saved not only the GHG emissions resulting from the manufacture of these items, but also the emissions associated with their disposal. A bag of normal saline was costing the dialysis unit £0.52, whilst a single giving set was costing £0.35. During the course of the 10,764 treatments provided per year, the use of online substitution fluid saves £9,364 (minus the very small, but less quantifiable, cost of producing the exact fluid volumes online).

Second Reduction

The amount of clinical waste produced was further reduced by improving segregation at source. The first measure had already removed a partially filled bag of normal saline (an average of 0.9 kg) and giving set (0.1 kg) from the waste stream, but the bicarbonate bag (1 kg) could also be diverted away from the clinical waste stream to domestic waste, giving an overall reduction in clinical waste of 2 kg per treatment, or 21.5 tonnes per year, and a financial saving of £6,458 (given a cost of £300 per tonne of clinical waste). This saving was offset by the increased cost of the domestic waste (£85 per tonne) attributable to the addition of the bicarbonate bag to this waste stream. As the provision of 10,764 treatments produces 10,764 bicarbonate bags, with a total weight of 10.764 tonnes, this cost was £914.90, resulting in an overall annual saving of £5,543.10.

The financial savings arising from these changes in practice have been reported. However, the associated reductions in GHG emissions have not been quantified. Although DEFRA has produced emissions factors for the procurement of medical equipment and pharmaceuticals (DEFRA, 2009], the limitations of their application to a narrow inventory of specific items have previously been discussed (Chapter 5, under the heading *Calculating Medical Equipment Procurement Emissions from Economic Activity Data),* and it is therefore anticipated that their use in the context of these initiatives (and those that follow in this chapter) may yield inaccurate results. However, the alternative strategy, in which the emissions attributable to the procurement and disposal of these items are determined from an analysis of their constituent materials, is beyond the scope of this chapter.

Reuse

The contraction of prion disease through medical procedures is extremely uncommon, and the risk of death from iatrogenic Creutzfeldt-Jakob disease has been estimated to be less than 1 in 10,000,000 per year [Hotchkiss, 2009]. Yet this minute risk has provoked the adoption of precautionary principles and disposable medical equipment has become ubiquitous. The financial implications are outweighed only by the environmental concerns. The discrepancy between the aim of maintaining health by negating the already miniscule risk of infection, and the acceptance of the degree to which this approach contributes to the arguably greater threat to health presented by climate change, has been highlighted within other specialties [Somner et al., 2010], perhaps most eloquently through the description of the Nipper Mountain [Hotchkiss, 2009]. It is also evident across renal healthcare, where it is likely that single-use equipment will become increasingly prevalent until infection control risk management strategies become more sympathetic to the health threats posed by climate change.

Concerns around infection resulting from equipment reuse are lower when the patient remains unchanged - the example of dialyser re-use has been discussed in detail in Chapters 2 and 5. The reuse of many items in renal units becomes possible with only a little re-organisation. For example, plastic sharps carriers for bedside venous cannulation can be washed and re-used and should be chosen in preference to paper trays [McGain et al., 2010], whilst plastic sharps containers can be reused if they can be safely emptied into a central collection point. Many suppliers will collect and re-use the pallets and cardboard boxes in which dialysis supplies are delivered. Patients might be encouraged to use the internet resource, Freecycle (www.uk.freecycle.org), to pass on the cardboard boxes containing medical supplies delivered to their home.

Recycle

The key to successful recycling, the segregation of waste at source, is infrequently achieved in the healthcare setting. One case study within the NHS showed that approximately 50% of the waste treated as clinical waste should have been considered to be domestic waste, and 35% of this was recyclable [Olko & Winch, 2002]. The survey reported in Chapter 3 revealed that less than one third of renal services recycle any plastic and packaging waste from single-use dialysis equipment. Among those services which do recycle, more than half estimated that they recycle less than 40% of the waste, perhaps as a result of the previously mentioned absence of recycling bins for plastic and packaging waste in clinical areas. However, the case studies described below illustrate that recycling can lead to financial, as well as environmental, savings.

Recycling Cardboard and Plastic Waste

An assessment by the waste management team at the Runcorn Road satellite dialysis unit in Birmingham identified two separate, but not uncommon, problems. The first problem was the disposal of the plastic acid containers, which were needlessly entering the clinical waste stream. The second problem was the disposal of the large amounts of cardboard packaging associated with the clinical supplies purchased by the unit. This was entering the domestic waste stream but was not being recycled. Moreover, collections were infrequent and the cardboard was frequently accumulating in piles. As well as taking up valuable space, these piles were identified as a fire risk, prompting the facility's leaseholder to cover the resulting increases in insurance costs with higher rental fees. The solution to all of these problems was the purchase of a baling machine to compact the waste.

Figure 13. The baling process during the disposal of cardboard and plastic acid containers.

The machine (Figure 13, picture 1) is housed in the storage room adjacent to the dialysis unit and measures approximately 1.8 metres by 0.9 metres by 0.9 metres. Used acid containers are emptied, rinsed with tap water and collected in bags holding eight containers (picture 2). These bags are then baled together, along with bags containing other plastic waste collected within the unit (picture 3). Ten bags are baled together, with cardboard layers at the top and bottom, to produce packages that weigh approximately 19 kg and are held together with binding tape (picture 4). Excess cardboard is baled together in separate packages weighing around 10 kg. The machine is operated by a single staff member for 20-30 minutes each day. The plastic and cardboard packages are collected on a weekly basis, free of charge, by a local company which recycles them. Were they not baled on-site, this would not prove economically viable for the company and collection would not be possible.

Investment Appraisal

The Runcorn Road unit generates 270 empty acid containers per week, resulting in 4.2 tonnes of plastic waste per year and a disposal cost of £3,150 per year. The unit also produces approximately 1 tonne of cardboard per year. The saving resulting from the free collection of this cardboard, in place of the costs associated with the domestic waste stream, has been estimated at around £1,000 per year. So the annual saving to the dialysis unit (equivalent to the overall cost of the original waste disposal methods) is approximately £4,000. The cost of a baler (£3,500) and its annual running costs (£195 maintenance, £342 binding tape, £50 plastic bags) means the total cost incurred during the year of implementation is £4,087, with an annual cost of £587 thereafter. The Runcorn Road unit therefore recouped the outlay cost at one year, and has been saving around £4,000 thereafter. These savings do not include the other plastics that are baled, and would be even greater in units using plastic bicarbonate containers.

Conclusion

The preceding chapters have focused upon an exploration of the different ways in which the provision of renal healthcare impacts upon the environment (Chapters 2 and 3) and studies to quantify the extent of some of these impacts (Chapters 4 and 5). In contrast, this chapter seeks to illustrate how the environmental impact of renal healthcare might be reduced through widely achievable measures. Furthermore, in recognition of the fact that, in many cases, the sustainability agenda may not be a priority for those with the responsibility for determining how renal healthcare is provided, care has been taken to describe any additional benefits offered by the initiatives that have been reported (such as reductions in financial cost and improvements in patient experience).

Opportunities to reduce the use of resources exist at all levels of the provision of renal healthcare. Strategies to lessen resource use at the level of individual patient care (for example, the opportunities to reduce and recycle the medical equipment and packaging used during a haemodialysis treatment) are likely to be most evident to those healthcare professionals with direct patient contact. Although the environmental benefits of such interventions may be relatively modest, the early experiences of the Green Nephrology Programme suggests that the associated benefit of engaging those healthcare professionals that are providing clinical care in environmental issues may make an important contribution to the development of the movement towards more sustainable healthcare.

Meanwhile, the case studies describing the use of heat exchangers and the conservation of reject water in dialysis services illustrate how simple changes to existing technologies can reduce the environmental impact at the level of standardised treatments. Whilst those staff routinely using and, particularly, servicing and maintaining equipment (for example, renal technicians) might be well placed to identify opportunities of this nature, manufacturers must also be encouraged to incorporate sustainability considerations into their products, and those within the healthcare services responsible for procuring medical equipment and facilities should seek to incentivise this.

However, the greatest environmental savings within renal healthcare will almost certainly result from the inclusion of sustainability as an important consideration during service reconfigurations. The nature of the providers of healthcare, the resources available to these providers, their understanding of what constitutes optimal healthcare in the light of ongoing medical research, and the needs and demographics of the patients that they serve, are all constantly evolving and changes in the way that healthcare is provided are therefore common. The case study describing the delivery of outpatient services by telephone consultation illustrates how service reconfigurations can support the transformation to more sustainable renal healthcare. Whilst the environmental benefits reported in this case are comparatively modest, it should be noted that the strategy was considered to be applicable to only a small cohort of patients (those with stable renal transplants) who were accessing the services on a relatively infrequent (quarterly) basis. Instead, service reconfigurations of the care of those patients using services frequently (for example, recent recipients of renal transplants or patients undertaking maintenance haemodialysis) or in high numbers (for example, all inpatients or all outpatients) might be expected to offer greater environmental benefits.

Chapter 7.

Conclusions.

This thesis has explored the direct environmental impact of providing renal healthcare. Particular consideration has been given to the contribution being made to GHG emissions in recognition of the relatively recent appreciation of the impact of anthropogenic climate change upon global health. This concluding chapter reviews the key findings of the thesis. The influence of these findings upon the ongoing efforts to reduce the environmental impact of renal services in the United Kingdom is discussed. Further recommendations for the translation of these findings into service provision are made, and suggestions for the direction of future research are outlined.

In Chapter 2 it was established that there has been very little research published on the environmental impact of renal medicine. Despite this, several examples of improvements in the sustainability of renal medicine were identified. In each case, the impetus for change had been a perceived benefit to one or more of the quality domains in healthcare, as defined by the Institute of Medicine [Institute of Medicine, 2001], rather than a primary intention to reduce an environmental impact. This chapter therefore demonstrated an important principle – that the transformation to the delivery of more sustainable renal healthcare may be realised alongside, rather than instead of, improvements in the quality of healthcare.

The opportunities to reduce the environmental impact of healthcare may not always be readily apparent. The application of the principles of clinical transformation, outlined in Chapter 2, as a framework to identify opportunities is therefore to be encouraged, particularly during service reconfigurations. The use of these principles within renal medicine has been illustrated in Chapter 2.

The results of the survey reported in Chapter 3 provided the first assessment of the extent to which sustainable practices are presently incorporated into the delivery of renal healthcare. A set of opportunities for sustainable practice were identified from a number of sources, including the results of the literature search (reported in Chapter 2), staff working within the renal services (including clinicians and members of the Estates and Procurement departments), and members of the renal industry. The practices of the majority of the renal services across England, Scotland and Wales were surveyed to establish a baseline of practice. Feedback was provided to participating units by way of individualised annotated slide sets. These slide sets included the aggregated national results and, to facilitate comparison, the data submitted by the individual unit.

Perhaps the most important finding of this survey was the confirmation that the opportunities to improve the sustainability of renal services are not only numerous but also varied in nature. The survey results also help to identify those aspects of the delivery of renal healthcare in which these opportunities arise. It is clear, for example, that many of the opportunities to improve sustainability will not be realised through strategies that focus primarily upon the direct energy consumption of a renal service, but might best be achieved through reconsideration of the way in which clinical services are delivered. This requirement for a clinical transformation has been a central theme within the thesis.

However, whilst it is evident that there is considerable scope to improve the sustainability of renal healthcare, the survey did not attempt to quantify, or indeed compare, the magnitude of each potential opportunity to enhance sustainability. It follows that an improved understanding of not only the magnitude of the overall environmental impact of renal healthcare, but also of the contributions made by the different components of this impact, is required to ensure the prioritisation of the most effective strategies.

Such quantitative information might also allow future versions of the survey to attribute appropriate weighting to the different opportunities for improvements in sustainability. In this way, the survey may then act as a tool with which individual renal services might more accurately determine the areas in which to focus strategies to reduce their environmental impact. Such a survey may also, in time, allow the sustainability of different renal services to be comparisons. This public benchmarking of the variation in practice between different renal services could be developed in line with the Renal Registry, which currently provides a clinical equivalent, and might be anticipated to drive improvements in performance.

The contribution of renal healthcare to GHG emissions represents an aspect of the overall environmental impact for which quantitative data can readily be determined. Furthermore, guidance on the magnitude of the reductions required in these emissions already exists [NHS Sustainable Development Unit, 2009]. Realising the targets set by the NHS Carbon Reduction Strategy within renal healthcare will require an improved understanding of the GHG emissions associated with the delivery of healthcare. The studies detailed in Chapters 4 and 5 have shown that the determination of the carbon footprints, including direct and indirect emissions, of both medical services (such as the Dorset Renal Service) and treatments (such as haemodialysis) is possible through adherence to the principles and definitions described within an existing methodology which is already in use across other sectors. In some places it was considered pragmatic to tailor the methodology of PAS2050 in order that it might more accurately reflect the carbon footprint of what the service or treatment under consideration was widely understood to include. Any such alterations, for example the inclusion of the emissions attributable to patient and staff travel, have been carefully outlined in this thesis. To date, there has been no proposed standard to which carbon footprinting methodologies within healthcare should adhere. This thesis therefore offers an innovative template for future studies of this nature across different specialties.

Improvements in the efficiency with which resources are used will not, in themselves, realise sufficient reductions in the GHG emissions associated with healthcare and, instead, a transformation of the current systems and practices used to deliver healthcare will be required. Carbon footprinting studies must play an important role in the evaluation of the environmental benefits of such service reconfigurations. Where appropriate, carbon footprinting studies should be aligned with the more traditional forms of healthcare research, for example, those designed to assess parameters such as the clinical efficacy and financial cost of treatments and services. This will allow their value to be judged against their carbon burden. Further research might consider how best to aggregate clinical, economic and environmental data. However, improvements in the sensitivity and accuracy of the carbon footprinting studies incorporated into these analyses will be necessary in order to provide meaningful comparisons and to show change over time. A pressing requirement is therefore the development of more specific emissions factors. This is of particular importance within the subsectors of pharmaceuticals and medical equipment given their significant contributions to the carbon footprints reported in this thesis.

The undertaking of future carbon footprinting studies within healthcare would be greatly facilitated by the more ready availability of activity data. Hospital trusts must be encouraged to implement the simple measures, such as sub-metering of electricity consumption in renal units, regular auditing of waste disposal, and the use of more refined procurement data recording systems to support this need. The Green Nephrology Programme is now piloting the integration of the reporting of this data within existing data collection processes through the Scottish Renal Registry (personal communication with Dr Jamie Traynor, Consultant Nephrologist, Monklands Hospital, Airdrie, April 27th 2011; also see http://www.srr.scot.nhs.uk/About/Guide.htm). Similarly, the development of an open access database has been proposed, into which the providers of renal healthcare products will be encouraged to enter information pertaining to their products, such as the carbon footprint of the product, the materials used and the opportunities for recycling the product and its packaging.

The determination of the GHG emissions arising from the provision of renal medicine across England represents the first estimate of an individual specialty's contribution to the carbon footprint of NHS England and provides the context in which many of the findings of this thesis must be considered. Renal medicine produces approximately 200,000 tonnes of CO_2eq per annum, which equates to around 1% of the carbon footprint of NHS England [Sustainable Development Commission, 2008] and over 2% of the emissions attributable to secondary care [Eastern Region Public Health Observatory, 2010]. Given the relatively small numbers of patients treated directly by the specialty, and therefore included in these footprints, renal medicine appears to have a disproportionately high carbon footprint. These findings support the assumption that renal medicine is an appropriate specialty in which to introduce the process of clinical transformation, as the Green Nephrology Programme has sought to do.

Procurement contributes 60% of the GHG emissions attributable to NHS England [Sustainable Development Commission, 2008]. Reducing these emissions represents a major challenge and will require collaboration between clinicians, commissioners and the industry. To date, this challenge has not been effectively met. A few of the many potential and realised barriers within renal medicine have been outlined in Chapter 3, and many of these will also be application to other clinical specialties. The results of the study reported in Chapter 4 suggest that the contribution of the procurement sector is even greater within renal medicine. This is potentially the most important finding of the thesis, as it emphasises the importance of addressing these emissions and has resulted in the formation of the Renal Sustainable Procurement Working Group within the Green Nephrology Programme. This group provides a forum in which the relevant parties can collaborate. The author developed a set of sustainable procurement criteria appropriate to the renal industry, and their use (in a slightly revised form) is now being piloted in a number of contracts being tendered by English renal services.

In addition to driving forward the inclusion of sustainability criteria within the contracts that renal services put out to tender, the publication of the results of the studies reported in Chapters 4 and 5 [Connor, Lillywhite et al, 2010; Connor, Lillywhite et al, 2011] is also encouraging the renal industry to accurately calculate the carbon footprints of the products which it develops in anticipation of the need fulfil these orders (correspondence with Derek Wiebenson, Senior Manager, Renal Global Marketing, Baxter Healthcare Corporation, by email, 21st April 2011; correspondence with Patrick Ward, Business Development Manager, Quanta, by email, 4th March 2011).

Although there are apparent advantages in the use of sustainability criteria as a factor contributing to the award of a contract, this approach may prove problematic. Difficulties arise in ensuring that the sustainability criteria are afforded adequate weighting amongst the other criteria such as financial cost and product quality. The use of sustainability criteria in this manner is also complicated by the European Laws on Fair Trade. Early experience from the work of the Renal Sustainable Procurement Working Group suggests that the inclusion of the criteria as part of a “supplier development programme” may be a more effective alternative. In this way, the successful suppliers are committed to reducing the environmental impact of their products and services over the duration of the contract. Because this approach will also reward providers for future improvements as well as for present performance, it may also allow the more meaningful inclusion of product-specific criteria by helping to negate the benefits of ‘creative accounting’ of emissions attributable to a particular product to other aspects of an organisation’s resource use.

The delivery of different aspects of patient care within the NHS is subject to constant change, for which there are many drivers. This is well illustrated by the provision of haemodialysis. In the 1960s, access to haemodialysis was limited to small numbers of patients at few, geographically disperse, centres. Technological constraints meant that dialysis treatments were typically 8 hours long. Treatments were undertaken in hospital and the dialysis membranes were reused. In the late 1970s, technological developments allowed a reduction in typical treatment times to 4 hours and the treatments were increasingly undertaken at home, such that this became the norm. The subsequent development of single-use, disposable, items of medical equipment has underpinned a dramatic rise in the availability of haemodialysis. This has, in turn, contributed to the development of an increasingly elderly and frail population of haemodialysis patients, who once again dialyse predominantly in-centre. Dialysis membranes (now known as dialysers) are no longer reused in the United Kingdom whilst, for clinical reasons, there is a revived interest in more frequent and longer sessions of dialysis.

As was the case with the developments in clinical practice reported in Chapter 2 as examples of more sustainable healthcare, none of these changes in the provision of haemodialysis services have been driven by the sustainability agenda. Furthermore, although the importance of sustainability within healthcare is increasingly appreciated, it is not strongly incentivised at present and consequently is likely to remain a low priority for the majority of individual renal services in the immediate future. Vigilance is therefore required to identify the opportunities to implement more sustainable models of care that arise from the need for service reconfiguration driven by other influences, of which financial pressure is perhaps currently the most significant.

The case studies reported in Chapter 6 have illustrated how the sustainability, care quality and cost-saving agendas may be aligned. However, in order that such opportunities may be taken, tools must be developed to allow the timely and uncomplicated evaluation of the environmental impacts of potential models of care. The ideal of detailed carbon footprinting studies, such as those reported in this thesis, is unlikely to be practical in every case. Indeed it may not be necessary because the use of indicative carbon burdens for standard episodes of patient care, such as those determined for inpatient admissions and outpatient appointments (Tables 12 and 13), offers a more feasible approach. Further research might be directed towards the development of an open access library of indicative carbon burdens covering the more common episodes of patient care. These could then be used as the building blocks with which to model the carbon footprints of different models of care. Considerable overlap exists between this approach and that of the aforementioned product database, with information derived from the latter contributing to the development of individual indicative carbon burdens.

The provision of sustainable healthcare remains in its formative stages, the evidence base is small and there are many areas of uncertainty. A pragmatic approach is therefore required but assumptions should be tested wherever possible, as the benefits of a particular approach may not always be realised when it is applied generically. For example, moving healthcare 'closer to home' has been advocated as a key action to reduce GHG emissions [NHS Sustainable Development Unit, 2009] but this may not always hold true; the findings of the study reported in Chapter 5 suggest that the rising uptake of HHD, in its current form and using standard machines, is likely to increase, rather than decrease, the carbon footprint of haemodialysis programmes.

Through the example of the potential reduction in GHG emissions achievable by dialyser reuse, the same study illustrates a further important point. Whilst patient safety must undoubtedly remain the priority, the balance between the current profligate pattern of resource use and the extent to which the immediate risk of harm to patients (for example, through infection) should be minimised must be re-evaluated if the procurement emissions, which dominate the carbon footprints of renal services (Chapter 4), haemodialysis (Chapter 5) and the NHS as a whole [Sustainable Development Commission, 2008], are to be reduced effectively.

However, only when the health impacts of climate change are more widely appreciated is it likely that such an approach might be considered acceptable. In the meantime, other drivers for change must be identified to encourage renal services to adopt more sustainable methods. The development of a funding model that promotes sustainable healthcare must be a priority. Acute trusts within the NHS are currently financially rewarded for the services they provide though the PbR system [Department of Health, 2011]. A fixed tariff payment system which reimburses hospitals for the type and number of patients treated, PbR is primarily designed to encourage activity and clinicians already recognise that the system may create perverse incentives. For example, it may be financially preferable for the provider to manage patients as inpatients rather than outpatients [Patterson, 2010], although this will almost certainly generate higher GHG emissions. In this way, it might be argued that PbR does not actively support sustainable healthcare at the present time. Research is therefore required to develop new funding models within PbR.

More direct financial penalties or rewards also represent an obvious and potentially powerful incentive for change. One such opportunity may lie within the CQUIN (Commissioning for Quality and Innovation) payment framework. This is intended to make the quality of care a core value for providers [Department of Health, 2010(b)]. Within the CQUIN framework, up to 1.5% of the provider's income becomes conditional on quality and innovation measures. These goals are agreed at a local level between the provider (for example, a renal service) and the commissioning body, with at least one goal derived from each of four nationally-specified areas: safety, effectiveness, patient experience and innovation. The area of innovation offers an opportunity to incorporate sustainability measures into the provider's CQUIN goals. Where the benefits include financial savings, it may be necessary to split these between the renal service and commissioning body.

The transformation to more sustainable clinical services must be implemented by healthcare professionals. Although the Green Nephrology Programme successfully recruited Local Representatives in the majority of renal services across England, Scotland and Wales, many of these individuals reported difficulties in engaging influential colleagues within their departments in sustainability initiatives. Research to develop an improved understanding of the attitudes of renal physicians and healthcare professionals towards environmental issues, and climate change in particular, might improve the success of the future Green Nephrology Programme projects. However, the realisation of many of the possible opportunities for more sustainable renal healthcare requires the involvement of only a few committed individuals within a renal service, and it may be that educational resources should be focused upon those with an active interest in the subject, provided that they are also encouraged to develop leadership roles.

In conclusion, this thesis has, for the first time, systematically explored the environmental impact of providing renal healthcare. Examples of good practice in the delivery of more sustainable renal medicine have been identified and, in a few cases, fully evaluated as case studies. The extent to which these, and other, sustainable practices are included in the provision of renal services across England, Scotland and Wales at the present time has been reported. The carbon footprints of both an individual renal service and, by extrapolation, the provision of renal healthcare across England, have been determined. Similarly, the carbon footprint of a common form of treatment for renal disease, haemodialysis, has been reported. The results of these studies are already shaping the carbon reduction strategies employed within renal medicine throughout the United Kingdom. Moreover, the work can also serve as a template for studies in other specialties.

Appendix 1.

A Description of Renal Services for Non-Clinicians.

The primary functions of the kidneys are the removal of the waste products of metabolism from the body and the regulation of fluid balance through the production of urine. An individual's kidney function is commonly reported as the glomerular filtration rate (GFR), which may be estimated from their serum creatinine level (determined by a blood test), age, gender and ethnicity, but can also be measured directly. The kidneys also contribute to the control of blood pressure, the production of red blood cells, and the maintenance of bone health. These functions also frequently deteriorate as a patient's GFR decreases. Patients with reduced kidney function may therefore develop a wide range of symptoms. These include the symptoms of fluid accumulation (eg breathlessness and oedema), the build up of waste products of metabolism (eg nausea, fatigue, weakness, itching), anaemia (eg fatigue, headaches, breathlessness) and metabolic bone disease (eg bone pain). Patients might also report symptoms indicative of the underlying cause of the renal disease.

The terms 'chronic renal failure' and 'chronic kidney disease' are used to encompass the many conditions that result in a relatively slow, and typically unrecoverable, reduction in the GFR. The more abrupt deteriorations, which may or may not be reversible, are described as 'acute renal failure' or 'acute kidney injury'. The term 'end-stage renal disease' (ESRD[§]) describes the total or near-total failure of the kidneys to undertake their primary functions, and may result from either acute kidney injury, chronic kidney disease, or a combination of the two.

For patients with ESRD, treatments exist that can partially replace the primary functions of the kidneys (the maintenance of fluid balance and the removal of metabolic waste products). The treatments are termed 'renal replacement therapies' (RRT) and include transplantation and the different forms of dialysis.

[§] End-stage renal disease (ESRD) is defined as either the requirement for renal replacement therapy (in the form of dialysis or transplantation) or a fall in the GFR to below 15 mls/min/1.73m^2.

Kidney transplantation is the treatment of choice for many patients. However, not all patients are suitable for transplantation. This, in conjunction with other factors such as the constraints on donor organ availability, results in around half of all patients receiving RRT in the United Kingdom undertaking dialysis.

The most commonly undertaken form of dialysis is haemodialysis (44% of prevalent RRT patients), with smaller numbers undertaking peritoneal dialysis (9% of prevalent RRT patients) [Byrne, Steenkamp, et al., 2010]. Although small numbers of patients undertake haemodialysis at home, the majority of patients receive thrice weekly treatments of around four hours duration in specialised dialysis units (either in hospitals or purpose-built 'satellite' dialysis units). During a haemodialysis treatment, a patient's blood is circulated through a machine which removes metabolic waste products and, if necessary, also free water. Patients undertaking peritoneal dialysis typically do so in their own home. In this modality, the patient's peritoneal cavity (a virtual space within their abdomen) is intermittently filled with fluid. Waste products within the patient's blood diffuse down their concentration gradient, across the peritoneal membrane and into this fluid, which is then drained away. The regular fluid exchanges are either undertaken manually during the day or by a machine overnight.

For an individual patient with ESRD, the modality of RRT may change over time. For example, they might begin by undertaking peritoneal dialysis, before later receiving a renal transplant. Should this transplant later fail, they might then revert to peritoneal dialysis or perhaps switch to haemodialysis. Although both forms of dialysis can also be used to treat severe episodes of acute kidney injury, haemodialysis is most commonly used for this purpose.

Renal services undertake the detection, diagnosis and management of renal diseases arising within the population that they serve, and typically require both inpatient and outpatient facilities. The provision of RRT programmes constitutes much of their workload, and requires considerable specialist personnel and infrastructure. Although haemodialysis is provided on an outpatient basis, the need for dedicated units is dictated by the specialist nature of the treatments, their duration and intensive frequency, and the number of patients requiring these services. The majority of patients receiving any of the forms of

RRT will, at one time or another also require inpatient services, and renal services therefore also provide ward-based inpatient care.

Inpatient services are also essential to other aspects of the workload of a renal service. For example, the provision of emergency renal care is predominantly inpatient-based and includes the management of patients with acute kidney injury. The early management of patients receiving renal transplants requires ward-based care. Patients with renal disease are also commonly admitted to inpatient beds to undergo medical investigations and procedures. The care of patients with renal disease can be complex and, for this reason, many patients with renal diseases are admitted under the care of the renal services when undergoing investigations into not only their renal conditions but also other unrelated conditions.

Patients are also often followed up through outpatient clinics – a further dimension to most renal services. Delivering these differing forms of care across differing forums requires renal services to employ a wide range of staff, including doctors, nurses, dieticians, physiotherapists, occupational therapists, social workers, administrators and managers.

The care of patients with mild renal disease is usually delivered in the primary care setting under the supervision of General Practitioners. Patients with more severe disease are likely to require referral to see a nephrologist (a doctor specialising in renal medicine) at the local renal service. Most renal services will provide the majority of the aspects of care described earlier, with the exception of acute transplantation surgery which is provided at tertiary referral centres.

At the time of writing, the Primary Care Trusts (PCTs) hold the financial resources and overall accountability for healthcare commissioning. Taking guidance where necessary from both the local Strategic Health Authority and from the Department of Health, PCTs negotiate contracts with local renal services to ensure that the hospital Trusts are appropriately reimbursed for the renal healthcare services that they provide. However, it is likely that responsibility for commissioning services will be passed to General Practitioners in the near future.

Until relatively recently, these negotiations resulted in 'block contracts' for particular services, with a resource allocation based upon historical activity and expenditure. In this way, a PCT would pay an agreed sum to a hospital Trust to provide particular services to their population of patients for a given period of time – irrespective of the number of healthcare episodes that subsequently arose. However, in England at least, the commissioning process is instead increasingly supported by the Payment by Results (PbR) system. PbR assigns national tariffs (fixed prices) to discrete episodes of healthcare (for example, one outpatient appointment, a single haemodialysis treatment). The tariff for a particular episode is derived from 'reference costs' reported by organisations across the NHS, and adjustments are made for market forces. Not all healthcare drugs, devices and procedures are presently included in PbR: for example, particularly costly drugs for which the demand is anticipated to be low but may be variable are commonly excluded.

A Fictional Patient's Journey.

No two patients with kidney disease are the same. Their experiences, and the care provided to them by renal services, vary considerably. The following vignette of a fictional patient's experiences of living with kidney disease is intended to illustrate some of the services provided and how they might be accessed, in order to provide a broader context to some of the areas covered in this thesis. The reader may find it helpful to refer to Figures 6 and 7 in Chapter 5.

Mr Smith first reported occasionally passing blood in his urine to his family doctor, Dr Jones, at the age of 24. Dr Jones identified that Mr Smith had high blood pressure, and undertook urine tests (which showed that Mr Smith was passing both blood and protein in his urine) and blood tests (from which it was ascertained that Mr Smith's kidney function was less than might be expected for a man of his age, with an estimated GFR of 52 mls/min/1.73m^2). Dr Jones referred Mr Smith to his local hospital to see a nephrologist, Dr Taylor, in the outpatient clinic, where a full history of his illness was taken and he was examined. Further blood tests were sent and Mr Smith was asked to attend the radiology department to have an ultrasound scan of his kidneys. At a follow up clinic appointment he was commenced on medications for his blood pressure and advised that he should have a kidney biopsy. Two weeks later he was admitted overnight to the renal ward for the procedure. At his third clinic appointment, he was told that the biopsy had confirmed that he had IgA nephropathy, a condition affecting the filters in his kidneys, and advised to remain on his blood pressure tablets.

Mr Smith's kidney function declined slowly but steadily over the next decade, despite the nephrologists adding further tablets for his blood pressure. During this time he continued to attend Dr Roberts' nephrology clinic, although he was often seen by other doctors from Dr Roberts' team, and, as his kidney function lessened, the appointments became more frequent. Before each appointment he would have a blood test at his family practice and the results would be reviewed at the hospital clinic. By the time his estimated GFR had fallen to about 30 mls/min/1.73m^2, Mr Smith was beginning to notice that he was more tired than normal. Dr Taylor told him that the levels of iron in his blood were low and he attended the renal day-case unit to have these topped up with infusions. A little later on he was started on fortnightly injections of 'epo', a medicine to boost the blood count. Initially he visited his family practice to have these injections, but he soon learnt to administer them himself. Around this time, Dr Taylor also asked Mr Smith to see the renal dietician at the clinic. She provided him with advice about eating healthily and safely with kidney disease. Mr Smith began taking chalky tablets with his meals to reduce the amount of phosphate he absorbed, as his kidneys could no longer remove it from his blood effectively.

Encouraged by his nephrologists (Dr Taylor had retired by now, and the team had expanded), Mr Smith began to use a computer system called Renal PatientView to access his own blood results online. When his estimated GFR reached about 20 mls/min/1.73m^2, the doctors began to talk about the different forms of RRT that might be needed in the future. He attended patient seminars at the renal unit to learn more, and began to log on to patient forums on the internet. By this time, he had begun to notice some swelling around his ankles and he was more breathless than he used to be. He had lost his appetite, was losing weight and was tired all the time.

It was clear that the best form of treatment for Mr Smith would be a kidney transplant. His brother came forward as a potential kidney donor and underwent blood tests at the renal department, but unfortunately he proved not to be a suitable match. Mr Smith was asked to go for more tests, including a heart scan, and was then activated onto the national transplant waiting list. However, over the next year, both his renal function and his symptoms deteriorated more rapidly and he and his nephrologists agreed that he should start dialysis.

Mr Smith had previously decided that, were dialysis to become necessary, he would prefer peritoneal dialysis. This decision was based upon the information he had gained from the outpatient consultations, patient seminars, educational videos he had been given, and also from what he had read online and gleaned from other patients. Just before his fortieth birthday, he was admitted to the renal ward at the hospital for a few days and underwent an operation to insert a peritoneal dialysis catheter into his abdomen. Two weeks later he started peritoneal dialysis, initially frequently coming up to the 'Peritoneal Dialysis Department' at the renal unit to see the 'Specialist Nurses' for training. Once he was established on this treatment he began to feel better in himself (although his blood tests did not look much different on Renal PatientView). Each day he would perform four 'exchanges', during which he drained fluid out of his abdomen and replaced it with new fluid from special 2.5 litre bags which were delivered to his house by a pharmaceutical company. He learnt to live with the restrictions this treatment put on his lifestyle but suffered an episode of 'peritonitis' – the result of bacteria contaminating the fluid he exchanged – that gave him severe abdominal pain and required a brief inpatient admission to the renal ward.

He remained on peritoneal dialysis for 11 months until, one day, he was called up for a kidney transplant. The operation was performed at the larger renal unit in the neighbouring city and he remained an inpatient there for ten days. Even after his discharge, he returned to attend the clinics in this other hospital twice a week for the first month. Then his care was handed back to his local renal service and nephrologists again. His medications had been altered completely. He no longer needed any tablets for his blood pressure or phosphate levels, but was now taking medications to stop his body rejecting the transplanted kidney. Gradually he was asked to come to outpatient clinics less and less frequently. A number of other tablets, to prevent opportunistic infections, were phased out.

Over the next few years, Mr Smith's care was provided exclusively through the outpatient department, with the exception of one admission to have his gallbladder removed (during which, once again, he was admitted to the renal ward).

Some seven years later, Mr Smith's blood tests began to show a steady deterioration in the function of his transplant. Initially this was managed through changes in his medications. Eventually he was again admitted to the renal ward and, after another ultrasound scan, he underwent a biopsy of the transplanted kidney. This showed that the disease that had originally affected his native kidneys was now beginning to affect the transplanted kidney. As time passed, Mr Smith once again began to develop the symptoms of chronic kidney disease, until twelve years after transplantation, it was agreed that he should go back on dialysis.

On this occasion, however, Mr Smith and his nephrologists agreed that he should have haemodialysis rather than peritoneal dialysis (partly for lifestyle reasons and partly due to his previous abdominal surgeries). He was booked into the renal day-case unit and underwent surgery to create a fistula in his arm. This took six weeks to mature, after which he began to attend the satellite haemodialysis unit near to his home. This large, open-plan building housed sixteen dialysis machines, individually supplied with purified water from a central water purification unit. The unit was open six days a week, and patients came in three sittings each day. Like most patients, Mr Smith dialysed three times a week for four hours at a time. At each treatment Mr Smith was weighed, and the amount of fluid to be removed from his body was calculated. Needles were inserted into his fistula and he was then connected to the dialysis machine by tubes. His blood was cycled through the machine and the metabolic waste products were washed out. He no longer passed much urine and his doctors encouraged him to restrict himself to one litre of fluid a day. Once again, the dieticians advised him on his eating habits, restricting his intake of certain foods.

Mr Smith found his dialysis days very tiring as a result of the travelling and the rigorous nature of the treatment. His nephrologist suggested he consider 'home haemodialysis' and the nursing staff at the dialysis unit began to teach him how to set up the dialysis machine, 'needle' his fistula and connect himself to the machine. Once he could perform his dialysis independently, his home environment was converted to accommodate a dialysis machine.

Mr Smith found that doing ‘home haemodialysis’ left him free to control the frequency and duration of his own dialysis treatments. Encouraged by the doctors and nurses at the renal unit, he began to dialyse more frequently. Instead of the thrice-weekly, four-hour treatments, Mr Smith undertook daily treatments of 3 hours, usually taking Sunday off. He noticed he needed fewer blood pressure tablets and felt less tired on this regime. After online forum discussions with patients in Australia, Mr Smith began to discuss the possibility of dialysing overnight, for eights hours every night, with his nephrology team. By this time, he was also back on the transplant waiting list again.

Appendix 2.

A full account of the methodology for the determination of the emissions data for waste.

The components of the Dorset Renal Service each produce waste. This waste is categorised as being either clinical or domestic waste. The disposal of this waste contributes to the carbon footprint of the Dorset Renal Service, although the model used in this study assigns the carbon embedded in products to the manufacturing process, and it is therefore included within the carbon footprint attributable to their procurement rather than their disposal (the ‘end of life’ carbon footprint has been calculated as opposed to the sum of the ‘end of life’ and ‘production’ carbon footprints).

The disposal of the waste produced by the Dorset Renal Service is assumed to be undertaken by the following three methods only; incineration, recycling, and landfill.

1. Waste that is incinerated

1.a. Clinical Waste

Estimation of the weight of clinical waste produced by the Haemodialysis and Peritoneal Dialysis Services

The weight of clinical waste produced per year by the haemodialysis and peritoneal dialysis departments has been estimated from the weight of clinical waste produced per patient per treatment [Hoenich et al., 2005] and the number of patients receiving these treatments in each department. It has been assumed that all haemodialysis patients dialyse thrice weekly and that all peritoneal dialysis patients undertake four exchanges per day. The nature and proportions of the constituents of the clinical waste arising from haemodialysis and peritoneal dialysis have been estimated from previous published studies [Hoenich et al., 2005] and from personal communication with the author of these studies (Dr Nicholas Hoenich, by email, 12th May 2010). DEFRA emissions factors for the incineration of waste have been applied to each of these constituents to determine their associated emissions [DEFRA, 2009].

Estimation of the weight of clinical waste produced by the acute inpatient ward

The weight of clinical waste produced per year by the acute inpatient ward has been estimated from the annual number of bed days and previous studies of the weight of clinical waste produced per inpatient per day [Audit Commission, 1997]. It has been assumed that the renal ward will generate similar amounts of clinical waste to other wards. In addition, the clinical waste attributable to the provision of four haemodialysis treatments per day has been included (as these include acute patients whose dialysis would not be accounted for in calculations for the other services). As acute patients are less commonly commenced on peritoneal dialysis, no contribution to the inpatient clinical waste has been assigned to this. The nature and proportions of the constituents of the clinical waste arising from acute inpatient ward has been estimated from previous studies [Hoenich et al., 2005] and personal communication with the author (Dr Nicholas Hoenich, by email, 9th March 2010). DEFRA emissions factors for incineration of waste have been applied to each of these constituents to determine their associated emissions [DEFRA, 2009].

Estimation of the weight of clinical waste produced by the Transplantation Services

The care of patients with renal transplants is encompassed by the acute inpatient service and the outpatient services. All waste produced in their care is therefore accounted for within these services.

Estimation of the weight of clinical waste produced by the administration departments

It has been assumed that the administration departments generate no clinical waste.

1.b. Domestic waste that is incinerated.

It has been assumed that segregation at source is imperfect, and that domestic waste enters the clinical waste stream and is incinerated. The amount of domestic waste entering the clinical waste stream has been estimated at 25% of the original volume of clinical waste produced by each component of the Dorset Renal Service. The nature and proportions of the constituents of the domestic waste entering the clinical waste streams of each of component of the Dorset Renal Service has been estimated from previous studies [Tudor et al., 2008]. DEFRA emissions factors for incineration of waste have been applied to each of these constituents to determine their associated emissions [DEFRA, 2009].

2. Waste that is not incinerated (disposal by recycling or landfill)

The weight of domestic waste produced by the different components of the Dorset Renal Service has been estimated from the respective weights of clinical waste and the assumption that 40% of all waste produced by the Dorset Renal Service is clinical waste and that the remainder is domestic waste (based on a previous study suggesting that 30% of all hospital waste is clinical waste [Askarian et al., 2004], and the assumption that renal medicine produces a higher proportion of clinical waste than the average), with the exception of the Outpatient Services, where is has been assumed that only 20% of all waste produced is clinical waste.

2.a. Domestic waste that is recycled.

For the purposes of this study it has been assumed that only half of the recyclable waste produced by the Dorset Renal Service enters the recycling waste stream. Published studies suggest 60% of all domestic healthcare waste is recyclable [Tudor et al., 2008]. Therefore, 30% of all domestic waste produced by each of the components of the Dorset Renal Service is considered to be recycled. The nature and proportions of the constituents of the clinical waste arising from the components of the Dorset Renal Service have been estimated from previous studies [Tudor et al., 2008]. DEFRA emissions factors for the recycling of waste have been applied to each of these constituents to determine their associated emissions [DEFRA, 2009].

2.a. Domestic waste that is sent to landfill

It therefore follows that, within each component of the Dorset Renal Service, 70% of all domestic waste is not recycled. This waste is sent to landfill.

It has been assumed that 40% of this waste is not organic [Tudor et al., 2008]. The nature and proportions of the constituents of this waste arising from the components of the Dorset Renal Service have been estimated from the findings of previous studies [Tudor et al., 2008]. Emissions associated with the disposal of this waste have been determined by the application of DEFRA emissions factors to these constituents.

The remaining 60% of the domestic waste that is not recycled is therefore assumed to be organic. In the acute inpatient ward (and, by assumption, also in the administration services), 25% of this domestic, non-recycled, organic waste is food waste [Tudor et al., 2008] and 75% is non-food waste. In the Outpatient Services, and by assumption also the Haemodialysis and Peritoneal Dialysis Services, the proportion of food waste falls to 8%. Emissions associated with the disposal of food and non-food organic domestic waste from each component of the Dorset Renal Service have been determined by the application of DEFRA emissions factors [DEFRA, 2009].

Appendix 3.

An assessment of the Carbon Footprint of the Dorset Renal Service using alternative emissions factors for pharmaceuticals and medical equipment.

The three sets of emissions factors applied to the activity data collected for pharmaceuticals and medical equipment in this study are outlined in Table 25 below.

Table 25. Emissions Factors applicable to pharmaceuticals and medical equipment.

	Pharmaceuticals		**Medical Equipment**	
Source of Emissions Factor	Emissions Intensity (kg/£ spent) for $C0_2$	Emissions Intensity (kg/£ spent) for $C0_2$eq	Emissions Intensity (kg/£ spent) for $C0_2$	Emissions Intensity (kg/£ spent) for $C0_2$eq
DEFRA [DEFRA, 2009]	0.62	0.81	0.45	0.57
National Statistics of Environmental Accounts [Sustainable Development Commission, 2008]	0.24	0.27	0.20	0.23
Averaged Emissions Factors	**0.430**	**0.540**	**0.325**	**0.400**

The results of the carbon footprint of the Dorset Renal Service, determined using the DEFRA emissions factors, are presented and discussed in the main text of Chapter 3. In this Appendix, the results of the carbon footprint derived using the two alternative sets of emissions factors for pharmaceuticals and medical equipment are presented.

1. An assessment using emissions factors from the National Statistics of Environmental Accounts.

Primary Sector Results

The calculated emissions for the primary sectors resulting from the application of **emissions factors from the National Statistics of Environmental Accounts** to the activity data for medical equipment and pharmaceuticals, are given below in Table 26.

Table 26. The emissions attributable to the primary sectors, determined through the application of the emissions factors from the National Statistics of Environmental Accounts to the activity data for medical equipment and pharmaceuticals.

Sector	**GHG Emissions ($kg\ CO_2eq$)**	**%age of GHG Emissions [a]**
Building Energy Use	381,331	20%
Travel	461,886	25%
Procurement	1,028,698	55%
Total Dorset Renal Service Emissions (Kg)	1,871,916	100%
Total Dorset Renal Service Emissions (tonnes)	1,872	100%

[a] Values rounded to nearest 1%

Sub-sector Results

The calculated emissions for the sub-sectors resulting from the application of **emissions factors from the National Statistics of Environmental Accounts** to the activity data for medical equipment and pharmaceuticals, are given below in Table 27.

Table 27. The emissions attributable to the sub-sectors, determined through the application of the emissions factors from the National Statistics of Environmental Accounts to the activity data for medical equipment and pharmaceuticals.

Sector	Subsector	GHG Emissions (kg CO_2eq)	%age of GHG Emissions
Building Energy Use		381,331	20.43%
	Total for Building Energy Use	**381,331**	**20.43%**
Travel	Staff Commuting	143,774	7.70%
	Staff Business	17,774	0.95%
	Patient Travel	279,293	14.96%
	Visitor Travel	20,448	1.10%
	Other Travel	598	0.03%
	Total for Travel	**461,886**	**24.74%**
Procurement	Pharmaceuticals	351,780	18.85%
	Medical Equipment	304,738	16.32%
	Diagnostics (Radiology)	209	0.01%
	Diagnostics (Pathology)	4,720	0.25%
	Paper	8,383	0.45%
	Food	6,933	0.37%
	Laundry Services	14,070	0.75%
	Construction	28,262	1.51%
	IT	5,268	0.28%
	Water	6,169	0.33%
	Sanitation Products	1,743	0.09%
	Waste	291,125	15.60%
	Total for Procurement	**1,023,400**	**54.83%**
Overall Totals	Kg	1,866,617	100%
	Tonnes	1,866	100%

2. An assessment using emissions factors averaged from those produced by the National Statistics of Environmental Accounts and from DEFRA.

Primary Sector Results

The calculated emissions for the primary sectors resulting from the application of **averaged emissions factors** to the activity data for medical equipment and pharmaceuticals are given below in Table 28.

Table 28. The emissions attributable to the primary sectors, determined through the application of the averaged emissions factors to the activity data for medical equipment and pharmaceuticals.

Sector	GHG Emissions (kg CO_2eq)	%age of GHG Emissions [a]
Building Energy Use	381,331	16%
Travel	461,886	19%
Procurement	1,593,401	65%
Total Dorset Renal Service Emissions (Kg)	2,436,619	100%
Total Dorset Renal Service Emissions (tonnes)	2,437	100%

[a] Values rounded to the nearest 1%

Sub-sector Results

The calculated emissions for the sub-sectors resulting from the application of **averaged emissions factors** to the activity data for medical equipment and pharmaceuticals are given below in Table 29.

Table 29. The emissions attributable to the sub-sectors, determined through the application of the averaged emissions factors to the activity data for medical equipment and pharmaceuticals.

Sector	**Subsector**	**GHG Emissions (kg CO_2eq)**	**%age of GHG Emissions**
Building Energy Use		381,331	15.65%
	Total for Building Energy Use	**381,331**	**15.65%**
Travel	Staff Commuting	143,774	5.90%
	Staff Business	17,774	0.73%
	Patient Travel	279,293	11.46%
	Visitor Travel	20,448	0.84%
	Other Travel	598	0.02%
	Total for Travel	**461,886**	**18.96%**
Procurement	Pharmaceuticals	697,720	28.63%
	Medical Equipment	528,800	21.70%
	Diagnostics (Radiology)	209	0.01%
	Diagnostics (Pathology)	4,720	0.19%
	Paper	8,383	0.34%
	Food	6,933	0.28%
	Laundry Services	14,070	0.58%
	Construction	28,262	1.16%
	IT	5,268	0.22%
	Water	6,169	0.25%
	Sanitation Products	1,743	0.07%
	Waste	291,125	11.95%
	Total for Procurement	**1,593,401**	**65.39%**
Overall Totals	Kg	2,436,619	100%
	Tonnes	2,437	100%

Considerable variation exists between the emissions factors quoted by different sources for the medical equipment and pharmaceutical supply chains. The impact of this variation, which is emphasised by the extent to which these subsectors contribute to the carbon footprint, is illustrated in Figure 5 within the main text of Chapter 4.

Appendix 4.

Inventory of the Consumables Used during the Provision of Haemodialysis (ICHD or HHD) using a Standard Machine.

The consumable items of medical equipment used during the provision of haemodialysis using a standard haemodialysis machine are listed in table 30.

Table 30. The consumable items of medical equipment used during the provision of haemodialysis using a standard haemodialysis machine.

Item	Constituent Materials	Optimal Waste Stream for each item	Constituent Materials of Associated Packaging	Optimal Waste Stream for Each Piece of Packaging
Blood Lines	PVC	Incineration	Paper	Recycling
			Low density Polyethylene	Recycling
Dialyser	Polycarbonate shell	Incineration	Low density Polyethylene	Recycling
	Synthetic fibres: polyamide/nylon			
	Polyurethane 'glue'			
Saline 1L	Polypropylene	Landfill	High density polyethylene	Recycling
	Polyethylene			
	Polyamide			
	Saline solution			
Giving Set	PVC	Incineration	Paper	Recycling
	Polycarbonate		Low density Polyethylene	
Acid Cartridge	Acid Solution	Landfill	Low density Polyethylene	Recycling
	General Plastic			
Bicarbonate	Bicarbonate solution (BiBag 650g)	Landfill	Low density Polyethylene	Recycling
	Polypropylene			
Fistula needles	Stainless steel	Incineration	Paper	Recycling
	PVC		Low density Polyethylene	Recycling
	Polycarbonate			
2x 10 millilitres syringe	Polypropylene	Incineration	Paper	Recycling
			Low density Polyethylene	Recycling
2 pairs of disposable gloves	Rubber	Incineration	Paper	Recycling
Apron	Low density Polyethylene	Incineration	Nil	N/A
Kidney Dish	Paper	Incineration	Nil	N/A
2 x Gauze packs	Polypropylene film	Incineration	Paper	Recycling
2 x plasters	Polyurethane	Landfill	Paper	Recycling
2 x dressing towels	Paper	Recycling	Low density Polyethylene	Recycling

Appendix 5.

Inventory of the Consumables Used during the Provision of HHD using a Mobile NxStage Machine.

The consumable items of medical equipment used during the provision of haemodialysis using a Mobile NxStage haemodialysis machine are listed in Table 31.

Table 31. The consumable items of medical equipment used during the provision of haemodialysis using a Mobile NxStage haemodialysis machine.

Item	Constituent Parts	Constituent Materials	Optimal waste stream for each item	Constituent Materials of Associated Packaging	Optimal Waste Stream for Each Piece of Packaging
Cartridge	Blood Lines	PVC	Incineration (although individual constituent parts may be recyclable, they cannot easily be detached from those parts requiring incineration).	One polythene packet	Recycling
	Dialyser	Polycarbonate shell			
		Synthetic fibres: polyamide/nylon			
		Polyurethane 'glue'			
	Cassette Tray	Polystyrene			
	Plastic Wallet	General Plastic			
SAK (a disposable container in which the dialysate is stored and produced). [One SAK used for every 2 treatments undertaken at *home*.]	Bag	Low density Polyethylene	Landfill (the constituent parts cannot currently be recycled and are not easily segregated).	One polythene packet	Recycling
		PVC			
		Nylon			
	Locks etc	Polycarbonate			
	Tubing	PVC			
5 Pre-packaged fluid bags of dialysate [5 bags required for every treatment *away* from home]	Bags	PVC	Landfill (the constituent parts cannot currently be recycled and are not easily segregated).	5 high density polythene packets	Recycling
	Dialysate solution	Dialysis Solution			
	Tubing	PVC			

Table continued overleaf.

Table 31 continued…

Item	Constituent Parts	Constituent Materials	Optimal waste stream for each item	Constituent Materials of Associated Packaging	Optimal Waste Stream for Each Piece of Packaging
Fistula needles		Stainless steel	Incineration	Paper	Recycling
		PVC		Low density polythene	Recycling
		Polycarbonate			
2 x 10 millilitres syringe		Polypropylene	Incineration	Paper	Recycling
				Low density polythene	Recycling
2 pairs of disposable gloves		Rubber	Incineration	Paper	Recycling
Apron		Low density Polyethylene	Incineration	Nil	N/A
Kidney Dish		Paper	Incineration	Nil	N/A
2 x Gauze packs		Polypropylene film	Incineration	Paper	Recycling
2 x plasters		Polyurethane	Landfill	Paper	Recycling
2 x dressing towels		Paper	Recycling	Low density polythene	Recycling
PAK (Disposable Filter) [Assumed to be changed every 10 weeks.]	Paper	Polycarbonate shell	Landfill (although individual constituent parts may be recyclable, they cannot easily be detached from those parts that are not).	One cardboard box	Recycling
		Synthetic fibres: polyamide/nylon			
		Polyurethane 'glue'			
	Conductivity cell & locks etc	Plastic			
		Metal			
	Canisters	ABS plastic			
	cannister media	Activated carbon			
	ion exchange resin	Polystyrene			
	Tubing	PVC			
	Electrical wiring	Plastic			
		Copper			
	Outer casing	Polystyrene			
		Plastic			

Appendix 6.

Electricity Consumed by Water Treatment Systems in ICHD Facilities.

Electricity use by the pump

In the Dorset County Hospital dialysis facility water treatment system, a water pressurising pump, powered by a 1.5 kWh motor, runs for 20 hours a day at an estimated 90% of its capacity, and idles for the remaining four hours (during which time it is assumed that the pump draws a negligible amount of electricity). The pump therefore draws (20 x 1.35) 27 kWh of electricity per day, six days a week. The pump therefore draws (27 * 6) 162 kWh of electricity each week, during which 165 ICHD treatments are provided. Therefore the energy use of the pressurising pump is 0.98 kWh per ICHD treatment. It follows, therefore, that the provision of 156 ICHD treatments to an individual patient over the course of one year will draw (156 * 0.98) 152.88 kWh.

Electricity use by the reverse osmosis plant

The Dorset County Hospital dialysis facility water treatment system uses two Gambro 104s reverse osmosis systems running in tandem. Each reverse osmosis system has a pump, valves and membranes. The power consumption is stated as 2.2 kWh for each pump and 2.5 kWh for each reverse osmosis system in total. Therefore, the Dorset County Hospital reverse osmosis plant draws a total 5 kWh of electricity per hour. The reverse osmosis plant runs from 0545 hrs to 0100 hrs on Mondays, Tuesdays and Fridays (a total of 17.25 hrs), and from 0545 hrs to 2000 hrs on Tuesdays, Thursdays and Saturdays (a total of 14.25 hrs). The weekly running time is therefore 94.5 hours, during which it draws a total of 472.5 kWh, whilst supporting the provision of 165 ICHD treatments. The electricity drawn by the reverse osmosis plant and attributable to the provision of one ICHD treatment is therefore 2.86 kWh. The provision of 156 ICHD treatments to an individual patient over the course of one year will therefore draw (156 * 2.86) 446.16 kWh.

Electricity used to maintain the temperature of the stored pure water above 60 °C

In the Dorset County Hospital dialysis facility, the purified water is stored in a 330 litre tank. In order to maintain the water temperature above 60 °C, the water is heated to 63 °C eight times each day (and allowed to cool spontaneously) on six days of the week, and six times on the day of the 'loop disinfection' cycle. Making the assumption that the process is 100% efficient, the energy required for this process has been calculated using the formula *Energy Used = C x M x Δ T*, where: C = specific heat capacity of water (4.19 J g^{-1} K^{-1}); M= the mass of water being heated, in g (330 litres of water equates to 330 kg or 330,000 g); and ΔT = the change in temperature required, in °K or °C (3 °C).

Energy used = 4.19 J g^{-1} K^{-1} x 330,000 g x 3 °C = 4,148,100 watt seconds or joules.

Therefore, the energy used to heat the 330 litres of stored water from 60 °C to 63 °C is (4,148,100 / 3,600,000) 1.152 kWh. Therefore, the energy used to maintain the stored water at or above 60 °C for one week is [(1.152 x 8 x 6) + (1.152 x 6 x 1)] 62.208 kWh. In one week, this water will support the provision of 165 ICHD treatments. Therefore the energy required to store the heated water for one treatment is (62.208 / 165) 0.3770 kWh. Finally, therefore, the energy attributable to storing heated water to provide one patient with one year of ICHD treatment (156 sessions) is (156 * 0.377) 58.815 kWh.

Electricity used during loop disinfections

During the periodic 'loop disinfections', the stored water is heated from 60°C to 90 °C and pumped through the pipe-work supplying the haemodialysis machines. It has been assumed that loop disinfection is undertaken on a weekly basis and that the process described is 100% efficient. The energy required to heat the water has once again been calculated using the formula *Energy Used = C x M x Δ T,* where *ΔT* is now equal to 30 °C.

Energy used = 4.19 J g^{-1} K^{-1} x 330,000 g x 30 °C = 41,481,000 watt seconds or joules

Therefore, the energy used to heat the 330 litres of stored water from 60 °C to 90 °C on a weekly basis is (41,481,000 / 3,600,000) 11.52 kWh. Once heated to 90°C, the water is pumped around the loop. It has been assumed that a 1kW pump is used and that the process takes approximately 1 hour. Therefore a further 1 kWh of energy is used. A single loop disinfection therefore requires 12.52 kWh (11.52 + 1.0) and serves the facility for one week, during which time 165 treatments are provided. The energy consumed by loop disinfections and attributable to a single ICHD treatment is therefore (12.52/165) 0.0758 kWh. As such, the energy use attributable to the loop disinfections entailed in the provision of ICHD to one patient for one year is (156 * 0.0758) 11.8 kWh.

Appendix 7.

A comparison of the constituent materials method and the economic activity data method to determine the medical equipment emissions arising from a single haemodialysis treatment using a standard haemodialysis machine.

For the reasons outlined previously, the emissions attributable to the consumable items of medical equipment have been determined through the application of emissions factors from the ICE database to the weights of the constituent materials of these items. However, an alternative approach, using economic activity data and DEFRA supply chain emissions factors [DEFRA, 2009], is possible. Although the two approaches might be anticipated to produce differing results, any significant discrepancy would require further examination. For this reason, a comparison of the use of the two approaches to determine the medical equipment emissions for a single haemodialysis treatment using a standard haemodialysis machine has been undertaken.

The data sources and assumptions supporting the constituent materials method have been outlined previously. To determine emissions using economic activity data, the unit prices of the items of medical equipment were obtained from a combination of the British National Formulary [British National Formulary, 2010], the on-line services of dialysis and hospital equipment suppliers, and costings reported by the Procurement Department of a United Kingdom renal service (the Dorset Renal Service). The results are shown in Table 32 below. The DEFRA supply chain emissions factors include the emissions attributable to processes such as transportation and manufacturing [DEFRA, 2009], and the 10% uplift factor used in constituent materials method is therefore not required.

The two approaches produce very similar results when used to determine the emissions attributable to the medical equipment required to provide a single treatment using a standard haemodialysis machine. These results therefore support the use of the constituent materials method to determine the emissions attributable to the medical equipment used in Mobile HHD technologies (for which economic activity data were anticipated to reflect emissions less consistently).

Table 32. The medical equipment emissions arising from a single haemodialysis treatment using a standard haemodialysis machine.

		Economic Activity Data Method			Constituent Materials Method		
	Constituent Materials	**Financial Cost Deflated to 2004 prices (£)**	**DEFRA Emissions Factor (kg CO_2 per £)**	**CO_2 Emissions (kg CO2)**	**Weight (kg)**	**ICE Supply Chain Emissions Factor (kg CO_2 per kg weight)**	**CO_2 Emissions (kg CO_2)**
Blood Lines	PVC	4.46	0.45	2.01	0.336	2.41	0.80976
Dialyser	Polycarbonate shell	6.24	0.45	2.81	0.192	6	1.152
	Synthetic fibres: polyamide/nylon				0.118	6	0.708
	Polyurethane 'glue'				0.005	3	0.015
Saline 1L	Polypropylene 33%	0.44	0.45	0.20	0.008	2.7	0.0216
	Polyethylene 33%				0.008	1.94	0.01552
	Polyamide 33%				0.008	2.53	0.02024
	Saline solution				0.494 [a]	0.62 [b]	0.30628
Giving Set	PVC	0.89	0.45	0.40	0.016	2.41	0.03856
	Polycarbonate				0.012	6	0.072
Acid Cartridge	Acid Solution	2.36	0.45	1.06	2.65 [a]	0.62 [b]	1.643
	Plastic (unclear)				0.294	2.53	0.74382
Bicarbonate	Bicarbonate solution (BiBag 650g)	1.60	0.45	0.72	1.8 [a]	0.62 [b]	1.116
	Polypropylene				0.084	3.9	0.3276
Fistula needles	Stainless steel	0.27	0.45	0.12	0.002	6.15	0.0123
	PVC				0.008	2.41	0.01928
	Polycarbonate				0.006	6	0.036
2x 10 ml syringes	Polypropylene	0.07	0.45	0.03	0.016	2.7	0.0432
Disposable gloves	Rubber	0.07	0.45	0.03	0.016	3.18	0.05088
Apron	Low density Polyethylene	0.03	0.45	0.01	0.005	1.7	0.0085
Kidney Dish	Paper	0.06	0.45	0.03	0.016	1.5	0.024
Disposable gloves	Rubber	0.07	0.45	0.03	0.016	3.18	0.05088
2 x gauze packs	Polypropylene film	0.22	0.45	0.10	0.006	2.7	0.0162
2 x plasters	Polyurethane	0.09	0.45	0.04	0.002	3	0.006
2 x dressing towels	Paper	0.27	0.45	0.12	0.004	1.5	0.006
	Total			7.715			7.26262
	10% (for manufacturing energies, distribution etc)			Not appropriate			0.726262
	Overall Total			7.715			7.988882

[a,b] for the constituent materials method, the emissions attributable to the procurement of the pharmaceutical grade fluids (saline, acid and alkali) have been determined from economic activity data [a] (in £) and DEFRA pharmaceuticals emissions factors [DEFRA, 2009] [b].

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