A LIFE CYCLE ANALYSIS OF LIVING

Measuring behaviour and the impact of dwelling rather than the dwelling alone

BY

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Preface

This thesis is submitted for the degree of Doctor of Philosophy at Victoria University of Wellington. The basis of this thesis is an assessment of how human behaviour and choices we make in our households affect total impact. The research described herein was conducted under the supervision of Professor R. J. D. Vale and Professor B. A. Vale in the School of Architecture and Design, Victoria University of Wellington, between May 2013 and May 2017.

My research question was formulated together with my supervisors. The research was difficult, but conducting extensive investigation has allowed me to answer the question that we identified. Certainly, I would have never reached the point of finishing my thesis without the help and support of others. These four years have been a challenging trip, with both ups and downs. Fortunately, I was not alone on this road but accompanied by experts, always willing to coach, help, and motivate me. For this, I would like to kindly thank them.

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I hope you enjoy your reading.

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Abstract

This research addresses the need for a more sustainable way of living by arguing that the current approach to green architecture, limited by the current criteria, needs to be refined in response to the needs of the finite world. In comparison with earlier ways of living, modern society has a large dependence on technology. This dependence only further reinforces the overall detrimental environmental impacts of human behaviour. The original contribution to knowledge this thesis contributes is to establish the effect of behaviour on the total impact of a dwelling by measuring behaviour in the act of dwelling in New Zealand households.

The thesis maps human behaviour; first looking at global practices and raw materials extraction: and second New Zealand's interaction with the global market. The inherent relationship between manufacturing nations and countries like New Zealand entails an indirect link revealing how international policies can be influenced by the average New Zealand household.

By means of an in-depth life cycle assessment, approximately 400 households are examined to identify the embodied energy in the act of dwelling, including ownership of the various household items that use finite raw materials in both operation and manufacture. This research identifies the existence of crucial "*Hidden Emissions*" that are currently not considered in national and international CO₂ accounting methods. This research also identifies the links between appliance ownership, its usage and how these vary for different types of appliances.

The outcome of this research posits, first, a theoretical framework for establishing impact as a result of behaviour, dubbed the "*Effect on Operation*" formulae, making it possible to measure behaviour in total emissions and how this impacts climate change. Second, this work identifies key changes in both the energy generation sector and in household behaviour to meet current emissions reduction targets. The hypothetical reduction scenarios presented in this thesis identify the possibility of a prospective change in the relative importance of embodied energy when compared to the impact of operational energy. This reveals a possible future in which embodied energy may well account for over sixty per cent of total emissions associated with household behaviour, suggesting several avenues for further research.

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List of abbreviations

ABS	Acrylonitrile Butadiene Styrene
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATD	Attention to Detail
BBQ	Barbeque
BSI	British Standard Institute
BRANZ	Building Research Association of New Zealand
BREEAM	Building Research Establishment Environmental Assessment Method
CO ₂	Carbon dioxide
CRT	Cathode Ray Tube
CPM	Centre for Environmental Assessment of Product and Material Systems
CFL	Compact Fluorescent Bulb
CSI	Construction Specification Institute
DOE	Department of Energy
DPL	Digital Light Processing
EMAS	Eco-Management and Audit Scheme
EE	Embodied Energy
EECA	Energy Efficiency and Conservation Authority
EPA	Environmental Protection Agency
EU	European Union
GWh	Gigawatt hours
gha	global hectare
GBP	Great British Pound
GDP	Gross Domestic Product
HVAC	Heating Ventilation and air conditioning
HVAC-R	Heating, Ventilation, Air Conditioning and Refrigeration
HDTV	High Definition Television
HDPE	High Density Polyethylene
HEEP	Household Energy End-Use Project
IKEA	Ingvar Kamprad Elmtaryd Agunnaryd
ISO	International Organization for Standardization
ICE	Inventory of Carbon and Energy

kg	Kilograms
KJ	Kilojoules
kt CO ₂ -e	Kilotonnes carbon dioxide equivalent emissions
KWH	Kilowatt-hours
KwH/yr	Kilowatt-hours per year
LEED	Leadership in Energy and Environmental Design
LEED - ND	LEED for Neighbourhood Development
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LED	Light Emitting Diode
LCD	Liquid Crystal Display
LPG	Liquid Petroleum Gas
L	Litres
LDPE	Low Density Polyethylene
MVHR	Mechanical Ventilation Heat Recovery
MDF	Medium Density Fibreboard
MJ	Mega Joules
Mt CO ₂ -e	Million tonnes of carbon dioxide equivalent emissions
NABERSN	National Australian Built Environment Rating Scheme New Zealand
Z	
NMA	National Mining Association
NZ	New Zealand
NZD	New Zealand Dollar
FRST	New Zealand Foundation for Research Science and Technology
NIWA	National Institute of Water and Atmospheric Research
NZGBC	New Zealand Green Building Council
NZIER	New Zealand Institute of Economic Research
OE	Operational Energy
OECD	Organisation for Economic Co-operation and Development
PVC	Polyvinyl Chloride
PSR	Product Specific Rules
SAIC	Scientific Applications International Corporation
sq metres	Square metres

USBM	U.S. Bureau of Mines
UFE	Unaccounted for electricity
UK	United Kingdom
UNFCC	United Nations Framework Convention on Climate Change
UNU	United Nations University
USGBC	United States Green Building Council
USA	United States of America
WEEE	Waste Electrical and Electronic Equipment
WWF	World Wildlife Fund/World Wide Fund for Nature

Chapter Summaries

The first chapter is an introduction to the thesis topic. It posits the theory that behaviour plays a significant role in the total environmental impact of a New Zealand household. However, the measurement of this household behaviour is difficult to quantify and is thus the central focus of this thesis. The broad range of literature presented in this chapter focuses on the current criteria for 'sustainable' design which covers construction and operation. This identifies that the effect of behaviour is currently considered very poorly and when it is mentioned there is no measurement of its impact. Here Mithraratne's graphs are presented along with Alcorn's work. These are the most recent New Zealand specific examples that begin to measure impact of house construction and operation. This chapter identifies that these (and the various examples from literature presented earlier in the chapter) do very little to measure the impact of behaviour.

In order to understand household behaviour today, the second chapter looks at consumer societies and the materials consumption, both historically and today, in manufacturing nations and in New Zealand. This identifies trends in materials use and industries that affect manufacturing. This chapter identifies that New Zealand is predominantly a service orientated economy that relies, for many of its products, on the CO₂ intensive practices of manufacturing nations. Because of this, various Ministry data sources are examined to identify sectors in which emissions have increased recently to understand consumerism in New Zealand. This includes data and publications since 1970 up to 2016 from various ministry sources which are identified in the chapter, when these are mentioned. These are different because the New Zealand government has seen many ministry changes over this period (closure of the Ministry for the Environment, and the Ministry of Economic Development and the inception of the Ministry of Business, Innovation and Employment).

While all data from all these sources have been referenced, and the author has originals of downloaded documents and data, most links are now impossible to pinpoint on the ministry sites due to the changes mentioned above. The aforementioned examination of this data identifies that one of the major areas in which emissions have increased recently is the energy sector. As a result, the end of chapter two identifies that establishing the effect of household choices, which specifically relate to the energy sector, is the most appropriate way to understand household impact due to behaviour. Hence the measurement of impact

associated with appliance ownership and operation is established as the central focus of this thesis.

To better understand current consumption in New Zealand, chapter three conducts an analysis of historic electricity generation methods and total consumption. Detailed analyses of current electricity consumption and projected requirements establish the viability of a solely renewable electricity mix. This reveals significant reductions are possible by incorporating policy changes to implement a solely renewable electricity mix.

The rest of this chapter looks at the results of the unprecedented New Zealand Household Energy End-use Project (HEEP) study that can be used to begin to measure appliance use. Based on meta-analysis principles of a systematic review (Boland et al., 2014), any study specific to a field, with large data set, is of more value than a smaller study, the ten- year HEEP study is unprecedented in its size, duration and coverage of an entire nation. The HEEP study covers all household types: rural and suburban. However, inner city apartments and dwellings which make up less than one per cent of all households are not covered. This is discussed in detail in the limitations and further study section in chapter eight.

The key limitation of the HEEP study is the lack of specific usage measurements of household appliances. Nevertheless, the data collected in this study of appliance ownership, for just under 400 households, is the most comprehensive data set completed to date and the never before published HEEP appliance ownership data is used as the basis of a means to measure the impacts of appliance ownership and use.

These data, as a result, will be much more accurate than any data that the author could have collected during the scope of this Ph.D. study. After having established the key findings using this data in this study, yes, a more detailed survey or targeted study has the potential to be better than using the HEEP data but only after findings are established, pinpointing specific data that would be needed, as this thesis has found in the case of the “unknown increase” figures.

Chapter four establishes the research methodologies used to measure the impact of household behaviour based on the HEEP data. The method selected to measure impact of household behaviour is the use of a life cycle analysis (LCA) of all household appliances. A LCA requires specific guidelines to be followed. These are discussed in detail, identifying the key definitions needed to conduct the LCA and the data collection methods required. In order to understand

appliance use, an analytical framework is developed and the methods for establishing life cycle inventories (material quantities) and resulting embodied energy figures for all household appliances are identified. The methods for establishing data sets to use for material quantities and for embodied energy are identified.

The fifth chapter lists all the materials that are assumed to be in a representative sample of each appliance to identify the life cycle inventories (LCI) of all the appliances identified in the case study households. While a few of these are based on referenced materials or manufacturer's specifications, many appliances had no LCI data available, in these cases a 'tear down study' is conducted as outlined in the methodology chapter.

The sixth chapter identifies the operational energy use figures used to represent each appliance in a New Zealand household. Due to the vast differences between many appliances a sensitivity matrix is conducted for all appliances. Here, each appliance's energy use figure is established using multiple sources to formulate the best representative figure based on wattage of the appliance and estimated hours of use.

Chapter seven identifies the results of the life cycle analysis. The energy impact of appliance ownership is compared to the impact of the house for each HEEP case study. This identifies that appliances have a relatively small energy impact when compared to the energy impact of the initial construction and operation of the houses in which they are used. This chapter also identifies the reductions possible at the household scale that have the potential to significantly reduce this impact. The chapter then identifies the CO₂ emissions associated with appliance ownership and how this compares with New Zealand total CO₂ emissions. Finally, the chapter posits a series of ownership and usage changes and presents the CO₂ emission reductions these changes could achieve.

The final chapter identifies the conclusions, limitations and further research. This chapter establishes that behaviour in household appliance ownership has the potential significantly to reduce total emissions in New Zealand especially when these reductions are based on both human choice and policy. At the end of this chapter, limitations of the methodology are discussed with key reference to data availability.

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Chapter One

Introduction and Contextual Research

We are entering an increasingly dangerous period of our history; our population and our use of the finite resources of planet earth are growing exponentially, along with our technical ability to change the environment for good or ill. But our genetic code still carries aggressive and selfish instincts that were of survival advantage in the past. It will be difficult to survive the next hundred years let alone the next thousand.

- Professor Stephen Hawking (TED, 2008).

1.1 Introduction

What are we, who are we, and why do we behave the way we do, are questions from the very beginnings of humankind. From time immemorial, people have been fascinated about the origin of the human race, what constitutes a human individual and how we as a species have evolved into creatures governed by consumer societies and consumerist behaviours (Wuketits, 1990). Understanding human behaviour is a pursuit of knowledge that is deep-rooted in academic debate and philosophy, dating as far back as the writings of Aristotle in his treatise *De Anima* or *On the Soul*. (Hett, 1936, pp. 1-203) where he raised the concept later known as *Tabula rasa*. Although the concept was discussed as early as three hundred and fifty BCE, the term was only coined in the late sixteenth century by John Locke. *Tabula rasa*

(literally 'blank slate') refers to the epistemological idea that human beings are born without predetermined mental content and hence all knowledge comes from experience. (Moore, 2003).

Proponents of *Tabula rasa* generally disagree with the doctrine of Innatism which suggests that the mind is born with knowledge or genetic memory and they also favour the "nurture" side of the *nature versus nurture* debate when it comes to aspects of human beings' personality, social and emotional behaviour. The contemporary definition of this is best defined by sociologist Ashley Crossman (Crossman, 2014).

The nature vs. nurture debate is a longstanding controversy about the effects of biology and social systems on individuals and behaviour. The "nature" side of the debate argues that people are shaped primarily by genetics and biology. The "nurture" side argues that our participation in social life is the most important determinant of who we are and how we behave. (Crossman, 2014, p. 1).

'Nature versus nurture' in this context was popularised by Francis Galton, the modern founder of eugenics and behavioural genetics in 1875 (Royal Institution of Great Britain, 1875, pp. 227-231). Galton discussed the recognisable impact of environment and inheritable traits on social behaviour, ideas also discussed by Charles Darwin, in his book, *On the Origin of Species*. (Darwin, 1859). Professor Stephen Hawking's words presented at the beginning of this chapter seem to reflect a similar viewpoint to that of Darwin, at least in regard to behavioural instincts in our genetic code.

These ideas are part of a much larger philosophical debate that has, through history, been at the centre of much dispute and controversy. However, the aim of this thesis is not to advocate either for or against any existing assertion. The goal of introducing this thesis with philosophers such as Aristotle, John Locke and Charles Darwin, is to stress the importance of behaviour and its effects. The question of behaviour and how it impacts life on Earth is present today as much as it was during the lives of any one of these theorists. A theory that relates this question of behaviour with personal day to day practices is known as the tragedy of the commons.

An economic theory first presented by William Forster Lloyd, *the tragedy of the commons* describes a situation within a shared resource system where the behaviour of individual users acting independently and rationally according to their own self-interest is contrary to the common good of all users because it results in depleting that resource (Lloyd, 1833). Lloyd

used an example of the effects of unregulated grazing on common land. This theory was explored once again over a century later by Garrett Hardin in 1968 (Hardin, 1968, pp. 1243-1248). However, in Hardin's discussion, *commons* referred to the shared and unregulated finite resources such as atmosphere, oceans, rivers, fish stocks, or even an office refrigerator.

1.2 Contextual research in New Zealand

Global crises and trends that date back several decades have triggered an increasing awareness of the need for a more sustainable way of living (Goldsmith and Allen, 1972, p. 110). These trends can be linked with the manner in which humanity as a species has evolved over time. Knowledge of how human behaviour impacts on sustainable living is an area of study that is essential in identifying how to practice and develop more sustainable architecture. One current process for measuring sustainable living is the Ecological Footprint, a method to measure the human demand on the planet's resources, developed by Mathis Wackernagel and William Rees (Wackernagel and Rees, 1996). While there are other measures employed in this thesis such as energy expenditure and carbon footprints, (see chapter seven), the Ecological Footprint method established by Wackernagel and Rees is a measure that is used in much of the reported data discussed in this chapter. In order to understand this method, there are three units of measurement that must be first explained. These are:

- global hectares;
- bio-capacity;
- fair share.

One of the fundamental units of measure used by Wackernagel and Rees' method is the *global hectare*. One global hectare (gha) represents one hectare of land with the average productivity of all biologically productive areas (measured in hectares) on earth in a given year. (Ewing and Moore, 2010). Using this method of Ecological Footprint measurement the extent of overall consumption of the world's resources can be calculated by estimating the area of land that would be needed to provide them, on the basis that once finite resources have been consumed, all resources will have to come from the land. The amount of land required, the Ecological Footprint, is related to bio-capacity. Bio-capacity, referred to as the new wealth of nations (Ewing and Moore, 2010), is the ability of ecosystems to provide the resources people need whilst absorbing the wastes they create. In 2007 the world's bio-capacity was determined as 11.9 billion gha available for a population of 6.7 billion people, resulting in a *fair share* of 1.78

gha (the global fair share footprint is the Ecological Footprint which all people could have without exceeding the Earth's available bio-capacity if the available productive land area were shared out equally). In 2007 humanity altogether made use of almost fifty per cent more than this fair share, on average using 2.7 gha per person (Ewing and Moore, 2010). This situation is made possible by utilising non-renewable resources such as limestone, sand, gravel, oil, coal, uranium and natural gas. Consequently, this 'overshoot' is a condition that cannot last indefinitely due to the finite nature of these resources.

At 58.2 million global hectares in total, New Zealand as a nation has one of the world's largest bio-capacities per person, and currently uses only 39.4 per cent of this (Ewing and Moore, 2010). While this suggests a positive outlook, these data only indicate that the amount New Zealand uses is well below the nation's per capita bio-capacity which is far greater than the world average. Herein is the fundamental problem, as New Zealand is responsible for one of the world's largest Ecological Footprints of 5.17gha per person, enough to award the country the title of the world's sixth largest ecological liability (Ranking America, 2009). Ecological footprint data from the Global Footprint Network (shown in figure 1.1) serves to further substantiate this title for New Zealand, when the country's footprint data is comparatively viewed against the USA and similar nations.

With New Zealand, and countries the world over, claiming advances in the field of sustainable architecture, as shown in the discussion below, how are such large, and often rising, footprints created? What aspects of living are most culpable? Research has shown that buildings are responsible for 15-20 per cent of the New Zealand footprint (Mithraratne, 2013, p. 84), but

does this mean that building design alone can provide a meaningful reduction in the Ecological Footprint?

1.3 A question of behaviour

In 1999, the New Zealand Foundation for Research Science and Technology (FRST) contracted the University of Auckland to study current practices in the New Zealand residential construction sector and to identify ways to improve the ability of those involved in design and specification of houses. The aim was to enable them to predict the environmental impact of their decisions over the life time of the houses (Mithraratne et al., 2007). This thesis builds on this to address the effect of household occupant behaviour, which goes beyond the design and specification of houses. This also fills an important gap in the more recent FRST/MBIE-funded study (Peachey et al., 2010, p.2) of New Zealand households and lifestyles. This requires a detailed understanding of what aspects of a dwelling make up the environmental impact or sustainability of a dwelling, how to measure it, and where human behaviour comes into this measurement. The criteria for measuring sustainability have to be the starting point to investigate environmental impacts associated with household dwelling.

Today more and more trade literature for building materials and construction systems targets energy efficiency and longer life span as evidenced by the introduction of the 'GreenFormat' database, an online database organising sustainable trade literature, set up by CSI (Construction Specification Institute, 2014) in the United States. But more often than not, the contents of a dwelling, from appliances to the interior fit-out, may be replaced as a result of changing trends and fashion rather than as a result of them having reached the end of their life span. This is a significant issue to investigate as unlike commercial buildings such as office or retail spaces, what sets the dwelling apart is that changes to it are more likely to be governed by individual decisions and personal behaviour. The question this poses is, to what extent do these household decisions and behaviour affect the environmental impact of a dwelling? Understanding occupants' choices may help to establish how the environmental impact of behaviour could be quantified and also suggest possible behavioural measures which could be considered for application in the existing building stock in New Zealand. This is an area of research Mithraratne began to look into, suggesting occupants' choices would have a relative effect on household footprint, for example not having carpet in a dwelling and using hardwood floors will reduce impact as well as cost (Mithraratne et al., 2007).

What is already known, and has been defined for over two decades, is that the impact of building materials and of energy consumption are two governing aspects in how sustainable (or not) architecture is considered to be today (Fisher, 1992). In the discourse of sustainable development, architecture presents a unique challenge. Construction projects typically consume large amounts of materials, produce tonnes of waste, and often involve weighing the preservation of buildings that have historical significance against the desire for the development of newer, more modern, more profitable (and perhaps more sustainable) designs. The concept of sustainable construction, or green architecture, was discussed by Thomas Fisher in two of his five principles of environmental architecture, that characterised real world applications for green architecture:

- *Energy Efficiency. All possible measures are to be taken to ensure that the building's use of energy is minimal. Cooling, heating and lighting systems are to use methods and products that conserve or eliminate energy use;*
- *Good Design. All possible measures are to be taken to achieve an efficient, long lasting and elegant relationship of use areas, circulation, building form, mechanical systems and construction technology (Fisher, 1992, p. 25).*

As identified later in this chapter, much contemporary "green" architecture follows these two principles for minimising footprint that focus on energy of construction and design (Embodied Energy) and the energy consumed in the building's use (Operational Energy). However, there is at present very limited exploration of how the behaviour of its occupants impact on the footprint of a dwelling.

In 2007 a PhD thesis by Nalanie Mithraratne began to touch on the possible effects of behaviour by investigating critical factors that influence the life cycle performance of New Zealand houses. The investigation specifically identified the embodied energy of the dwelling construction and maintenance, operating energy and appliances and furniture inside the dwelling (Mithraratne et al., 2007, p. 166). This study presented evidence that energy consumption has a greater impact than the embodied energy of the building materials, but did not cover what the energy of the act of dwelling comprises, an aspect only discernible once the life cycle energy of appliances, furniture, interior fit-outs and dwelling usage (as a result of behaviour) are specifically investigated and quantified.

Figure 1.2: Life cycle energy of households (Mithraratne et al., 2007, p. 166).

Mithraratne et al. produced graphs such as shown in figure 1.2 that showed the embodied energy of the building in relation to the operating energy of various aspects such as heating and lighting. This is extremely valuable research as it begins to quantify the criteria currently used to evaluate the energy footprint of a dwelling and thus an important aspect of its sustainability. However the crucial gap in this information is how these figures would change as a result of behaviour. Or more precisely, what aspects of this life cycle energy are affected by behaviour and in which specific areas?

Much like Mithraratne, another researcher, Andrew Alcorn, examined the embodied energy of a house in order to conduct a study of the New Zealand residential building stock. In 1995 Alcorn undertook a series of embodied energy analyses to update the coefficients for New Zealand building materials initially published by Baird and Chan in 1983. Alcorn's analyses from 1995 to 2003 did not, however, apply the resulting coefficients of building materials to whole houses, or consider the specific role of human behaviour.

Alcorn presented the results of his research in a PhD thesis in 2010 which looked at a series of house designs in New Zealand and evaluated CO₂ emissions based on the embodied energy coefficients determined in his preceding study. While this research was extremely valuable, Alcorn's study did not investigate or present any evidence on the impact of human behaviour on sustainable living. This thesis is thus a further step in a 30 year research effort investigating the environmental impact of New Zealand houses. It is a study in which quantifiable data is

observed to identify and measure the effect of behaviour on the environmental impacts of household operation.

1.4 Aim of the research

As identified earlier in this chapter, over twenty years ago it was recognized (Fisher, 1992) that contemporary "green" architecture placed prominence on the energy used in making a building and its materials (embodied energy) and energy consumption of the building in use (operational energy), without significant identification of how and to what extent, compared to other aspects, behaviour could be increasing or reducing these aspects of a dwelling's overall impact on the environment. The general aim of this research is:

to understand how behaviour within a dwelling impacts on the total environmental impact of a New Zealand house.

This general aim will provide an understanding of the extent to which residential occupants' behaviour is significant or not in the overall search for more sustainable practices. The significance of such an investigation has the potential to provide quantified data that clearly identifies how much of a dwelling's footprint is comprised of impact resulting solely from the manner in which the occupants choose to use their living space. The ultimate point is to be aware of how the human condition or behaviour can affect the sustainability of design. This will then assist in determining where significance lies in regard to achieving truly "green" architecture.

1.5 Understanding the current criteria

As identified by researchers and theorists such as Holling (2000) and substantiated by Ewing and Moore (2010) there is an ever growing awareness of the massive changes that human societies are causing to environments leading to calls for a fundamental change in lifestyles (Holling, 2000). As identified in the following sections, concerned individuals, non-governmental organisations and even some governments call for more sustainable living and seek ways to make a transition from the current modern consumerist lifestyle to a more sustainable way. In this context – and especially from a human impact perspective – the home plays a vital role as the central point where the act of dwelling meets the dwelling itself. The

research in this thesis takes a closer look at the current evolution of the residential sector with a particular focus on the impact of human behaviour.

1.6 Defining sustainability

The term “sustainable development” was first widely articulated by the Brundtland Commission of the United Nations in 1987 and framed as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations General Assembly, 1987, p. 41). More than 140 alternative and modified definitions that have emerged since then have been identified by Johnston et al. (2007) and this proliferation of alternative definitions of the term “sustainability” has created a situation where this central concept has come to mean many things.

Subsequently, the original concept of ‘sustainable development’ has been widely acknowledged yet the definitions are extensively debated (King, 2011, p. 5; Lanoie et al., 2010; United Nations, 1987; Komeily and Srinivasan, 2015, p. 32). The significance of such a debate cannot be understated, with over seventy per cent of the world predicted to reside in urban environments in 2030, the demand for sustainable urban growth is paramount (Komeily and Srinivasan, 2015, p. 33; Haapio, 2012, p. 165). From these somewhat ambiguous definitions and principles, tools for assessing neighbourhood sustainability have been developed under the priority of creating healthy and “liveable” communities (Murayama and Sharifi, 2014, p. 244; Komeily and Srinivasan, 2015, p. 32; King, 2011, pp. 18-19). At the level of a basic definition, sustainability simply implies that a given activity or action is capable of being sustained (i.e. continued indefinitely).

This definition, however, conflicts with the idea of naturally evolving systems that change over time. It also points to a possible conflict between the idea of being sustainable and the idea of development. It is also difficult to apply to the environmental domain, where even highly damaging practices can be sustained within time frames that are seemingly indefinite in respect to the average human lifespan. An example of this is the use of nuclear energy. While this seems like a promising solution to the impending depletion of non-renewable forms of energy, uranium sources are just as finite as other fuel sources, such as coal, natural gas, and oil and are expensive to mine, refine, and transport, and produce considerable environmental waste (including greenhouse gases) during all of these processes (Shedroff, 2009, pp. 54-57).

Additionally, the resulting wastes last two hundred to five hundred thousand years. Some people also argue that ecosystems will in time (but maybe too late for the survival of the human species) adapt to the changes inflicted upon them as argued by Siegfried Fred Singer, an American physicist and emeritus professor of environmental science, in his controversial book, “Unstoppable Global Warming: Every 1,500 Years” (Singer and Avery, 2007). Thus it seems to be difficult to give a direct definition of sustainability or sustainable development and Robèrt et al. instead proposed the utilisation of four basic principles of sustainability (1997):

- Substances from the lithosphere must not systematically increase in the ecosphere.
- Substances produced by society must not systematically increase in the ecosphere.
- The physical basis for the productivity and diversity of Nature must not be systematically deteriorated.
- There should be fair and efficient use of resources with respect to meeting human needs.

These principles basically demand a minimal human intervention in natural processes (which is almost impossible given the rising human population) or the application of cyclic processes, which eventually give back what has been extracted. The latter approach is usually reflected in natural systems that are strongly intertwined in adaptive cycles of growth, accumulation, restructuring, and renewal and form an ever evolving eco-system (Holling, 2000).

The ideal state has been defined as a *panarchy*, which is the “structure in which systems of nature, of humans and combined human-nature systems are interlinked in never-ending adaptive cycles.” (Holling, 2000). Holling further identifies this as “the heart of what we define as sustainability” and goes on to acknowledge, “We recognise that human behaviour and nature’s dynamic are linked in an evolving system. We realise that the seeming paradox of change and stability inherent in evolving systems is the essence of sustainable futures.” (Holling, 2000).

Karl-Henrik Robèrt, founder of The Natural Step initiative, argues that “the only processes that we can rely on indefinitely are cyclical; all linear processes must eventually come to an end” (Robèrt, 1991, p. 4), which provides another idea about what 'sustainable' is and is not. He then also observes that society is continuously processing natural resources in a linear direction, which will eventually reach an end and thus is not sustainable. To ensure our own continued existence, he argues we will have to identify these linear processes and turn them into cycles.

This way, society may eventually reach a sustainable lifestyle driven by sustainable development and positive evolution.

In respect to Holling's theory of human behaviour, the research in this thesis theorises that as a step towards devising this sustainable lifestyle and positive evolution, the quantifiable impact of human behaviour must be determined when considering the overall environmental impact of a dwelling.

Sustainability research can thus be described as the seeking for both change and stability in evolving systems and the understanding of cycles and their scales to identify points to trigger positive change and foster resilience with respect to Robèrt's four basic principles of sustainability. What this means in detail, however, relates to the field to which it is applied and thus is still a subject for a final definition in the field of impact based on the act of dwelling, which will be examined later in the thesis, in chapter four when a methodology for assessing impact of behaviours is posited.

1.7 Sustainability in practice today

The notion of sustainable buildings and homes is not new, out of necessity for millennia buildings have been built embedded into their environment and made ready to evolve over time. Only recently, cheap energy, large glass sheets and air conditioning have been developed, transforming the art of building and loosening the relationship of the building to its surrounding eco-systems. Buildings are now often enough constructed not only without respect to their environment but also without respect for their inhabitants (Barnett and Browning, 1995).

In an earlier attempt to define sustainable homes with respect to these recent developments, Barnett and Browning came up with an eight-point checklist of criteria that a sustainable building has to meet. The list includes the usage of "environmentally friendly" resources for building and living, and harvesting water and energy in sustainable self-contained cycles that minimise consumption (Barnett and Browning, 1995).

Similarly, the Department for Communities and Local Government in the UK provided the "Code for Sustainable Homes" (Department for Communities and Local Government, 2006), a system of housing quality indicators that provides a framework to measure the sustainability of a home in nine key areas (again the primary principles were listed in much the same way as

described by Barnett and Browning): Energy and CO₂ emissions, water, materials, surface water run-off, waste, pollution, health and well-being, management, and ecology.

House building construction energy and the house's energy consumption are the primary factors related to the carbon footprint that are considered in this checklist for achieving sustainable design.

Figure 1.3: Current sustainability criteria considered for building footprint.

Figure 1.3 depicts the current criteria considered when evaluating the footprint of a dwelling. Sources such as Barnett and Browning (1995), Mobbs (2010), Wai (2003) and the Department for Communities and Local Government (2006) are not the only works stating this limited set of current criteria. Anderson et al. (2009) identified the way in which energy consumption and building characteristics are the two dominant aspects considered in this current model. Olivia Guerra Santin (2010) went as far as to start recognising the crucial missing pieces such as the influence of behaviour on energy consumption and also the influence as a result of systems incorporated in the building.

Using these criteria emphasis is placed on how a home's impact is defined based on checklists as used in the Code for Sustainable Homes. Other checklists similar to this also include additional factors such as the independent growing of organic food, the optimisation of ventilation and air flows, and providing a healthy living environment (Mobbs, 2010; Federal Government Department of Climate Change and Energy Efficiency, 2010; and Wai, 2003). Dwelling case studies complying with the different levels of the Code for Sustainable Homes are listed on their website (Sustainable Homes UK, 2013). This document describes the success of each project with a list of sustainable features (as shown for one project in figure 1.4) that are the only reason for their nomination as 'successful sustainable homes'.

Figure 1.4: Sustainable Homes UK: Checklist of success for a particular project.

This website also identifies some limitations in these case studies of supposedly "sustainable" homes. These limitations include the acquisition of building materials, solar collectors that generate a surplus during the day, but require buying additional energy at night or non-renewable natural gas that is often still used for cooking and water heating.

Often aiming at self-sufficiency, growing some food and owning animals are part of sustainable lifestyles, but inhabitants usually still have to acquire additional food and other provisions from external sources and the anticipated low ecological impact is sometimes cited as coming with less physical comfort for the inhabitants (Mobbs, 2010). This latter point is particularly noteworthy as it sheds light on the probability that choices made around building materials, maintenance cycles, heating patterns and temperatures and hot water consumption, all a result of human patterns of living, will, in fact, have an impact on the house's energy usage, and even on the building construction energy, both of which are usually considered to be fixed by the building form and fabric. This is an aspect not identified or quantified in the criteria by which the "sustainable" case studies listed in Sustainable Homes UK are categorised.

1.8 Current criteria and labelling systems

Similar criteria can be found throughout the world. Over two hundred "sustainable homes" opened their doors to approximately forty thousand people in September 2011 for Sustainable House Day in Australia (Australian Solar Energy Society, 2013). Several projects collect information about sustainable homes and communities and list more than one hundred and eighty "eco-settlements" in Germany (Global Ecovillage Network., 2013a), another four

hundred such settlements in Europe (Stengel and Kommerell 2009) and about five hundred “eco-villages” worldwide mostly outside of Europe (Global Ecovillage Network, 2013b).

There are a large number of sustainability rating schemes that attempt to achieve sustainable design using various points systems and criteria, with labelling systems that are widely recognised, fully-developed and established within their respective countries, and are being applied internationally (Finnveden et al., 2016, p. 202). These include labelling systems such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM).

1.8.1 LEED and LEED - ND

LEED was established in 1994. However, to go beyond the building, LEED for Neighbourhood Development (LEED-ND) was established in 2009, following the 2007 pilot version, as a collaboration of the United States Green Building Council (USGBC) with Congress for New Urbanism and the Natural Resources Defence Council (Haapio, 2012, p. 166; Ahmann et al., 2013, p. 21). Whilst considering the neighbourhood scale, LEED-ND also begins to look at communal behaviour. The current version has recently been upgraded to LEED-ND version four which launched in 2014 yet it did not fully take over until late October 2016 (Finnveden et al., 2016, p. 202). It is assessed and applied much like many of the schemes, through a points based system to determine the “relative sustainability of a new community or neighbourhood development” (Zofnass Program Team, 2012a, p. 179) through a third-party verification system (USGBC, 2014).

The scheme is set out slightly differently to its counterpart LEED Homes. It is comprised of three main areas: ‘Smart Location and Linkage’ worth twenty-eight points; ‘Neighbourhood Pattern and Design’ with an available forty-one points; and Green Construction and Technology’ with thirty-one, with two other minor categories for ‘Innovation’ and ‘Regional Design Credits’ (USGBC, 2014; Haapio, 2012, p. 166). These rating categories consist of prerequisites as well as credits which provide varying degrees of points based on their weighting (USGBC, 2014). These have been rationalized against a set of principles determined by the U.S Green Building Council in an attempt to achieve certain sustainable urban planning outcomes such as: compact, walkable and attractive communities; housing for various socio-economic groups; reduction in vehicular usage through alternative transportation; mixed land

use and a range of other initiatives (Benfield et al., 2011, p. 20). The scheme offers four levels of certification which encourage greater participation which conversely can also reduce the effectiveness of the outcomes (Haapio, 2012, p. 166).

LEED-ND has a hierarchical points system where some credits are worth more than others and can be selected across categories (USGBC, 2014; Murayama and Sharifi, 2014, p. 245). This is problematic for numerous reasons, yet primarily, credit selection will be determined by the highest score yield result. Therefore, the credits worth more points are likely to be selected against others which may have been more appropriate to the sustainability of the site (Garde, 2009, p. 425; Finnveden et al., 2016, p. 208; Knack, 2010, p. 19). An example of this could be the prioritization of walkability worth twelve points, which may not necessarily result in sustainable outcomes (just because a development is labelled walkable does not mean that its residents will walk), as opposed to ‘solar orientation’ worth only 1 point (USGBC, 2014; Murayama and Sharifi, 2014, p. 255). Proof of this can be seen in a study of the LEED-ND pilot projects by Garde (2009), and also in a separate analysis of a portion of LEED-ND certified projects by Murayama and Sharifi (2014) which analyses the percentage of criteria included in developments. The findings of these discovered a direct correlation between the credits worth more points being selected as a priority, as they are also less costly (Garde, 2009, pp. 429-430; Murayama and Sharifi, 2014, pp. 253, 255).

1.8.2 BREEAM

BRE Global initially launched BREEAM-C in 2008, with the most recent version in 2012 which is the focus of this study. Its certification structure provides any level of design with a certification, with a rating out of 5 stars, with the possibility of achieving no stars (BRE Global, 2013). BREEAM-C has more categories than LEED-ND, and has been considered to be more thorough in the scope of assessment by covering not only ‘Climate and Energy’, ‘Transport and Movement’, ‘Buildings’ and ‘Ecology and Biodiversity’, but also ‘Community’, ‘Place Shaping’, ‘Resources’ and ‘Business and Economy’, with additional points for ‘Innovation’ (BRE Global, 2016; King, 2011, p. 46). The aims of this scheme are to “ensure that its standards provide social and economic benefits whilst mitigating the environmental impacts of the built environment” (BRE Global, 2016, p. 1).

In BREEAM-C all credits have equal weighting within categories and are given a score out of 3 for each aspect of assessment depending on performance (BRE Global, 2016; Murayama and Sharifi, 2014). BREEAM-C does use a weighted system, yet it is used after evaluation by multiplying category results based on the regional criteria priorities (Murayama and Sharifi, 2013, p. 79). This emphasis on contextualization is seen as essential in creating a sustainable outcome which is suitable to its region, something which is severely lacking within the LEED-ND framework and therefore may result in incompatibility with local conditions (Garde, 2009, p. 438; Ameen, Li, and Mourshed, 2015, p. 123; Murayama and Sharifi, 2013, p. 79; Haapio, 2012, p. 169; Rees and Wackernagel, 1996).

1.9 The application of these criteria specific to New Zealand

The New Zealand Green Building Council aims to support sustainable practices in the built environment. The NZGBC is made up of three components which make up the available label and award schemes. These are: National Australian Built Environment Rating Scheme New Zealand (NABERSNZ), Greenstar and Homestar. NABERSNZ is a rating system which assesses the energy performance of office buildings on a scale from zero to six stars. Greenstar is a tool used to rate the sustainable performance of commercial buildings on a scale from four to six. Finally Homestar is a rating tool used to rate residential buildings on a scale from one to ten (New Zealand Green Building Council, 2016). In the Homestar rating tool, a rating of one implies that the building needs significant work and a rating of ten means a building meets international best practice. Most newly built houses in New Zealand receive a rating of around three or four, while most existing buildings in the New Zealand housing stock only receive a rating ranging from one to three. (New Zealand Green Building Council, 2016).

1.10 Problems of the current criteria

All of these rating systems, and the Sustainable Homes UK examples discussed earlier in this chapter, have a common issue in that their certification process ends at the project completion (Finnveden et al., 2016, p. 208; Komeily and Srinivasan, 2015, p. 40; King, 2011, p. 14). This concept is a problem considering that the sustainability of something is entwined within how it performs in the present and the future (United Nations, 1987, p. 12). This highlights the underlying issue as to how the sustainability of any household or project can be determined merely from the process of its design and construction (Murayama and Sharifi,

2013, p. 82; Finnveden et al., 2016, p. 208). Although there is currently little research assessing the long-term performance of LEED-ND certified projects; there have been numerous studies which reassess the outcomes of LEED certified green buildings such as Birt, Mancini, and Newsham, (2009) and Murayama and Sharifi, (2014, p. 244) in relation to energy use (Aranoff et al., 2013, p. 154). Studies such as these have identified large inconsistencies in the long-term performance of buildings accredited with these current labelling systems and therefore emphasise the need for a better evaluation of occupants' behaviour during the life of the building within the certification (Aranoff et al., 2013, p. 154; Navarro, 2009). The reoccurring theme in all of these examples that identify the current criteria for assessing sustainability is the substantial emphasis in them on building materials and energy consumption of the building itself. This is also inherently linked with the system boundaries for life cycle analysis as identified by Karimpour et al. in "Minimising the life cycle energy of buildings," a journal article published in 2013.

Figure 1.5: System boundaries that define embodied energy and operational energy (Ramesh et al., 2010, p. 1593) cited in Karimpour et al. (2013).

Cited by Karimpour et al., the systems boundaries that define embodied energy and operational energy were established by Ramesh et al. in 2010. These identify how various stages make up the embodied energy and operational energy. According to this process the embodied energy is the energy used to extract, process, manufacture and dispose/ recycle the material, while the operational energy occurs in the use of the manufactured product.

In *Sustainability in Energy and Buildings* (2013) analysis of sources of emissions by Mohammed et al, showed that across the EU at least forty per cent are from building (UNEP, 2007) with a corresponding figure of forty-four per cent in the UK (Carbon Trust, 2008). However, these data measure the emissions associated with the operational energy system boundaries as described by Ramesh et al. (Mohammed et al., 2013. p. 213). Mohammed et al., identify that this is because:

Traditionally, embodied CO₂ has been deemed optional in a lifecycle emissions assessment of buildings because it was estimated to be of a small magnitude compared with operational CO₂. (Mohammed et al., 2013. p. 214).

Shoubi et al., share this view stating that the consumption of operational energy by buildings has the single largest impact on the environment (Shoubi et al., 2015. p. 41). Hence, there are key differences to the effects of each of the system boundaries as described by Ramesh et al. The application of system boundaries and stages specific to this thesis methodology are discussed in greater detail in chapter five.

In a review by Mahsa Karimpour, Martin Belusko, Ke Xing and Frank Bruno, it has been found that embodied energy can be up to twenty-five per cent of the overall energy use of a building, and as residential buildings are becoming more and more energy efficient, e.g. the operational energy of the building is reducing, the embodied energy of the materials used in the home is becoming more important (Karimpour et al., 2013).

It is likely that behaviour impacts on both the use phase and the manufacturing phase that Ramesh et al. identify in the system boundaries of a life cycle energy analysis.

1.11 Knowledge gap

This thesis is not simply concerned with scrutinising the effect of behaviour on resource use. Instead, it proposes a comprehensive framework that can be used to explore and evaluate

the effect behaviour has on the embodied energy and the operational energy involved in living in a dwelling, in 'the act of dwelling'.

The need for a comprehensive framework arises from the lack of existing research on the subject of human behaviour and its effects on life cycle impacts and the act of dwelling. This need is discussed in greater detail in chapter two.

While there is a great deal of literature that explores a very definite link between human behaviour and resources use, there is no existing framework or understanding of how behaviour quantifiably increases the total impact. There is a need to determine how large the effect of behaviour is in a household and how significant this is in comparison to the impact of the house itself.

Herein lies the gap in knowledge; this literature review specifically identifies lack of a comprehensive framework as the main knowledge gap for quantifiably measuring the effect of behaviour in a household.

1.12 Research question

In the New Zealand context, recent works by Alcorn (2010) and Mithraratne et al. (2007) recognise that a significant part of identifying a building's environmental impact is based on building and construction energy (the embodied energy) and the energy consumption (the operational energy). Both the embodied energy and the operational energy are factors that are by definition behaviour related as identified by Santin (2010) and by Anderson et al. (2009), (as well as Sonderegger 1978 in earlier work).

Their research found that household characteristics, lifestyles, background, motivation, values and attitudes determine behaviour which in turn influences energy consumption. Behaviour might also be influenced by the interaction between the user and the systems in the building (Santin, 2010, p. 20).

These findings, coupled with the literature review presented in this chapter, identify that the effect of behaviour is poorly considered in assessing sustainability. Although existing models consider operating and embodied energy, what is not known is the degree to which behaviour affects operational and embodied energy. Most of the existing rating schemes are design-based

so they do very little to measure behaviour. As a result, the overarching research question posed in this thesis is:

To what extent does household behaviour, the act of dwelling, affect the life cycle impact of a New Zealand house in its totality?

This question is answered by first establishing how the total impact of a household can be measured, and the manner in which human behaviour comes into this measurement. Establishing these measurement methods, considering human behaviour, makes up a significant part of chapters three and four.

Second, this question is addressed by identifying the degree to which behaviour impacts a dwelling's energy consumption and embodied energy. This is the main focus of chapters five and six, which identify if behaviour and household decisions exclusively have an effect on embodied energy or on operational energy.

Finally, in order to understand the extent of behavioural impact in New Zealand households and to assist in forming conclusions regarding the thesis question, chapter seven identifies the results of this analysis for CO₂, and energy expenditure; in order to understand if behaviour change alone can make a significant change in the impact of the existing building stock?

1.13 Hypothesis

This thesis theorises that the calculation of the overall impact of a dwelling must consider the effect of behavioural choices on energy consumption in order to determine how significant the impact of individual decisions and personal behaviour may be on the overall performance of a dwelling.

Herein lies the importance of this research as it will determine quantifiable data for the act of dwelling not considered previously in the criteria for achieving sustainability, with its focus on the building rather than how it is occupied.

The "footprint" in figure 1.6 demonstrates the new sustainability model that the proposed research aims to quantify, in which the behaviour of the occupants both effects and overlaps with the operational and embodied energy of the household in what can be called "the act of dwelling".

Figure 1.6: Theorised sustainability model and question of behaviour.

The hypothesis of this research, then, is that:

Behaviour plays a significant role in how sustainably people live. This cannot simply be measured in terms of technologies employed as behaviour has the potential to affect both the embodied energy within a dwelling and also the operating energy based on individual decisions made by the occupants.

With the aim of the thesis identified earlier, this thesis also theorises that this behaviour, and its impact on household footprint, can be measured with a comprehensive framework and calculation methodology that this thesis will develop.

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Chapter Two

Consumer Behaviour: Global Scale Interaction

Environmental problems are multi-dimensional and can only be solved by multi-dimensional measures. The activities of any one country or individual have direct or indirect environmental repercussions on others. Policies must therefore be based on the recognition of global interdependence and be guided by the principle of joint responsibility.

- Joint members of the InterAction Council (InterAction Council, 1990).

2.1 The “where” of manufacture and operation

As presented in the quote above, the joint members of the InterAction Council established an international accord in 1990 identifying the need for policies to recognise the interdependence at the global scale for environmental issues addressed by any one nation. Established in 1983, the InterAction Council is an independent international organisation to mobilise the experience, energy and international contacts of those who have held the highest office in their own countries. (InterAction Council, 2017). To go beyond the emphasis on buildings explored in chapter one, this chapter focuses on industry practices and how these may potentially affect the total impact of a New Zealand household. It is at this point that understanding the “where” of manufacturing and operation is crucial. In order to broaden

understanding of the connection of behaviour with embodied energy of manufacturing, this chapter draws attention to the nation's interaction with the global materials economy, as any interaction with energy intensive manufacturing processes from around the world may carry with it a much larger environmental cost. Therefore, a basic understanding of the ecological effects of worldwide material consumption, and the rates at which raw materials are extracted throughout the globe is essential. This is a prerequisite to understand how to measure the effective impacts of both the international manufacturing and the operation within New Zealand, of these manufactured goods.

2.2 Worldwide material consumption

2.2.1 Consumer societies: From the 1950s to today

The rise of the consumer society, in tandem with rapid industrialisation and population growth, is considered to be at the root of the world's environmental crisis (Population Reference Bureau, 2015). The culture of consumption that has spread since mid-century from North America to Western Europe, Japan, and a wealthy few in developing countries has brought with it an unprecedented appetite for physical goods - and the materials from which they are made (Brown et al., 1994).

Residents of the industrialized world comprise only about twenty per cent of the global population, yet even twenty years ago they consumed eighty-six per cent of the world's aluminium, eighty-one per cent of its paper, eighty per cent of its iron and steel, and seventy-six per cent of its timber (Young and Sachs, 1994, p. 11). The same study showed that the average American in his or her lifetime accounted for the use of some five hundred and forty tons of construction materials, eighteen tons of paper, twenty-three tons of wood, sixteen tons of metals, and thirty-two tons of organic chemicals (Young and Sachs, 1994, p. 11).

Sophisticated technologies, frequently using fossil fuel powered machinery, have enabled extractive industries to produce the vast quantities of raw materials identified by Young and Sachs. Such technologies have helped to keep most materials' prices in decline. But the growing scale of those industries has also exacted an ever-increasing environmental cost. The production of raw materials has brought about unparalleled ecological destruction over the last half of the twentieth century (Young, 1992; Young and Sachs, 1994). This damage is hidden from view for most residents of wealthy countries. Few of the world's mostly city-dwelling

consumer class comprehend the impacts and scale of the extractive economy that supports their lifestyles, Young and Sachs (1994) identified the manner in which the production of virgin materials alters the global landscape at rates that rival the forces of nature.

Mining moves more soil and rock, an estimated 28 billion tons per year-than is carried to the seas by the world's rivers. Mining operations often result in increased erosion and siltation of nearby lakes and streams, as well as acid drainage and metal contamination by ores containing sulphur compounds (Young and Sachs 1994, p. 11).

Whole mountains, valleys, and rivers have been ruined by mining in Papua New Guinea, Peru, the United States, and many other countries. Smelters that process this mined material, if not carefully controlled, can release large quantities of arsenic, cadmium, lead, sulphur dioxide, and other toxic substances into the air. Proper smelter pollution controls are rare outside the more developed countries (Moore and Luoma, 1990). Former mine and smelter sites are often laced with heavy metals, acids, and other pollutants, and can remain contaminated for centuries. But even with proper pollution controls, policed in developed countries, many sites remain contaminated. For instance, in the United States, fifty-nine former mineral operations were slated for remediation under the federal Superfund hazardous-waste clean-up program, at a cost of billions of dollars. Many of them ranked, in the early nineties, among the most expensive sites to clean up (Moore and Luoma, 1991).

The environmental damage of materials extraction practices is not simply limited to the mining industries. Again, over twenty years ago Durning (1993) identified the effect global deforestation was having on the Earth's forests. Durning identified that this was a major concern as it was not limited to already developed nations:

The cutting of wood for materials plays a major role in global deforestation, which has accelerated dramatically in recent decades. Since 1950, nearly a fifth of the earth's forested area has been cleared. Of what remains, less than half is intact forest ecosystems, the rest is a fragmented mix of natural regrowth and commercial tree farms. Industrial logging has more than doubled since 1950, and is now particularly important in the destruction of primary rain forests in Central Africa and Southeast Asia (Worldwatch Institute 1993). Timber operations not only have direct impacts on the forests they cut, but also lead to additional clearing by ranchers, loggers, and

miners, who gain access to previously virgin territory by following extensive networks of logging roads. (Durning, 1993, p. 43).

2.2.2 Developed and developing nations

A recent article by Steege et al. identified that extractive practices such as the logging described above are still continuing and are not restricted by geographic restrictions or borders. As natural resource reserves dwindle in developed nations, the search for minerals and timber is increasingly colliding with the few areas of the globe that once remained relatively undisturbed by the outside world. Steege et al. found that as many as half of the tree species in the Amazonian forest may be threatened with extinction or heading that way because of massive deforestation (Steege et al., 2015). In tandem with deforestation, incursions into the forests by miners have created widespread environmental damage and brought new diseases to previously isolated native populations in remote areas of the Brazilian Amazon region. Over 25 years ago, at least fifteen per cent of one tribe, the Yanomami, were estimated to have died from malaria alone (Inter-American Commission on Human Rights, 1997).

Environmental impacts of similar extractive practices can be seen in industrialised countries as well. In the former Soviet republics of Kazakhstan and Uzbekistan, for instance, the production of agricultural crops such as irrigated cotton has contaminated large areas of farmland with pesticides and salt over the last eight decades (U.S. Dept. of Agriculture, 1994). Diversion of the region's rivers for irrigation has shrunk the Aral Sea by more than one-third and destroyed its fisheries. World cotton production has tripled since 1950 (Durning, 1993).

The chemical industry is another environmentally detrimental industry that has since 1950 become a major source of materials, including plastics, which have increasingly been substituted for heavier materials, and synthetic fibres, which have become crucial to the textile industry, as discussed by Lewis (1988). The impacts of chemical production, from hazardous-waste dump sites like Love Canal (Beck, 1979) to industrial accidents like the release of dioxin from a Seveso, Italy, plant in 1976 (Bertazzi et al., 1998) are generally more familiar than those from mining, logging, and agriculture, since chemical facilities are usually located closer to urban areas. Chemical manufacturing often leaves behind contaminated sites, and is the source of a large share of the hazardous waste produced by industrial societies (Lewis, 1988, p. 53).

Raw materials industries are also among the world's biggest consumers of energy. Over forty years ago, in the 1970s, mining and smelting technologies that did not improve for the next four decades, took an estimated eight to ten per cent of world energy use each year (Durning, 1992, p. 136). Just five primary materials industries, paper, steel, aluminium, plastics, and container glass, accounted for thirty-one per cent of U.S. manufacturing energy use. This thirst for energy contributed heavily to such problems as global warming, acid rain, and the flooding of valleys and destruction of rivers for hydroelectric dams (U.S. Bureau of Mines, 1994). Furthermore, today's newer mining and smelting technologies have made it possible to extract materials with more ease, for example the extraction of copper from large quantities of ore. These new technologies have not reduced the environmental cost that is observed today (JX Nippon Mining and Metals, 2017). A study conducted by the JX Nippon Mining and Metals group identified that next-generation smelting technologies still bear a high environmental cost since newer technologies that extract materials with greater ease require processing of the sulphur oxides released from the sulphur content of ores. The JX Nippon Mining and Metals company is a global mining group that has mining operations in Japan, Chile and Australia. Their study discusses current research and development of new, more environmentally friendly technologies, however, these are not currently implemented. (JX Nippon Mining and Metals, 2017).

The principal subject of debate over materials policy in recent decades has not been the environmental impact of the materials economy, but rather how soon non-renewable resources are likely to run out (International Energy Agency, 2015). But the ecosystems that surround these non-renewable resources could well collapse long before the non-renewable resources themselves diminish. (Zimring, 2012, p. 12). Through observing consumption on a global scale, this chapter identifies how unsustainable the current materials economy is, not so much because of the finite properties of materials but because the current rates of usage court human and ecological catastrophe. (Zimring, 2012, p. 385). Extractive activities caused severe local environmental problems even in Ancient Roman times but rates of raw materials production remained relatively low until after the Industrial Revolution (U.S. Bureau of Mines, 1994). Of course, large population increases have contributed to environmental degradation, simply because the number of people consuming at high levels has increased. But growth in the materials economy since the Industrial Revolution has far outstripped that of population. For example, world production of pig iron, the crude metal from which steel is made, was about

22,000 times greater in 1993 than it was in 1700 (UNDSD, 1993). During the same period, the world population grew by about eight times. In the United States, the Bureau of Mines estimated that total consumption of virgin raw materials was seventeen times greater in 1989 than it was in 1900, a period during which the country's population grew just over threefold (UNDSD, 1993).

The 1987 report of the World Commission on Environment and Development: *"Our Common Future"*, stipulated that this rapid increase in growth in materials consumption took place in the 1950s and 1960s. In chapter five of Agenda 21, it is speculated that this onset of rapid growth was triggered as a result of northern industrial countries developing their economies. (UNDSD, 1993). This entailed the construction of new homes, new roads connecting them with stores and offices, and thousands of factories for consumer goods such as refrigerators, stereos and automobiles.

Industrial production grew most rapidly between 1950 and 1973, with a 7 per cent annual growth in manufacturing and a 5 per cent growth in mining. Since then growth rates have slowed, to about 3 per cent yearly between 1973 and 1985 in manufacturing and virtually zero growth in mining. (United Nations General Assembly, 1987, p. 174).

With economic systems already established, growth in industrial nations' raw materials consumption has slowed since the 1970s (OECD, 2016. p. 2). There is speculation by some observers that these countries have reached a consumption plateau, since much of their materials-intensive infrastructure of roads and buildings is already in place, and markets for cars, appliances, and other bulky goods are largely saturated (Bomse et al, 1990). But does this plateau indicate the consumer culture is fading out? Donald Rogich of the U.S. Bureau of Mines (USBM), has theorized that though materials use as measured by weight appears to be levelling off in industrial countries, use as measured by volume may well still be on the rise, as lighter-weight materials such as synthetic polymers and paper are being used in greater quantities and are substituting for heavier substances such as metals (U.S. Bureau of Mines, 1991, p. 147).

Rogich's theory is supported by trends observed since the coming of the "chemical revolution" (U.S. Bureau of Mines, 1991) that introduced lighter weight materials into the manufacturing market, allowing heavier materials to be replaced by synthetic plastics and polymers. It would

be a complex process to ascertain whether or not the use of polymers would be environmentally preferable as an alternative to heavier materials like steel. The embodied energy contained in both steel and polymers, per kilogram, would need to be established to identify the effect this chemical revolution has had on environmental impacts.

Here, the impact of end of life emissions can potentially be quite significant. When it comes to polymers, this is an accurate assumption, as absorption back into the environment is a big part of the environmental cost of plastics that embodied energy does not consider. However, this is a topic recently researched in a Ph.D. thesis (Petrovic 2014). This thesis has this year produced a publication (Petrovic et al., 2017).

The “end of life” discussion of household materials and recycling is also covered in depth in recent household impact work and LCA studies (ICE version 2.0 Database, 2016; Hammond & Jones 2008; Hammond & Jones 2016; Alcorn 2010; Alcott 2005).

This thesis has deliberately stayed away from this topic as it is well outside of the scope of this thesis, for consistency it is not mentioned here. This is also the topic currently being explored in another doctoral thesis which has recently (August 2017) presented a thesis proposal.

2.2.3 Global materials economy and international legislation

With most infrastructure established, the demand for raw materials in developed countries may well appear to be levelling off, but worldwide usage indicates raw materials’ use is still steadily rising.

Between 1970 and 1991, total world materials consumption rose 38 percent. Consumption of agricultural materials grew 40 percent, forestry materials 44 percent, metals 26 percent, non-metallic minerals 39 percent, and non-renewable organic chemicals-the feedstocks for plastics and synthetic materials production-69 percent. The continuing increase in demand stems in part from population growth and in part from increasing per-person use of materials in newly industrialising countries. (U.S. Bureau of Mines, 1991, p. 147).

Acknowledged here by the U.S. Bureau of Mines in 1991, the steadily rising trend dating back to 1970 has not changed to date. A recent report published by an intergovernmental organisation with 35 member countries, the Organisation for Economic Co-operation and

Development (OECD) identified that *the last decades have witnessed unprecedented growth in demands for raw materials worldwide, driven in particular by the rapid industrialisation of emerging economies and continued high levels of material consumption in developed countries.* (OECD, 2016. p. 2). Material prices have continued to fall even as the environmental costs of the global materials economy have risen sharply, since the 1970s (World Bank, 1993). During the same period, throughout the world, almost every major commodity has grown significantly cheaper, a trend which, in turn, has allowed consumption rates to continue their steady growth (World Bank, 1993). The global materials economy saw a drastic rise at the turn of the century only to fall again over the past decade (World Bank, 2014, p. 8) in effect having no influence on materials consumption. Today the price outlook for metals depends considerably on China's growth prospects, as the country consumes almost half of global metals supplies (World Bank, 2014, p. 2). This is hardly unexpected as China and the United States of America are the world's two largest manufacturing nations (Meckstroth, 2015).

Rank	% of World Manufacturing		Valued in U.S. Dollars	
	2013	2013	2003	1993
1	23.2%	China	United States	United States
2	17.2%	United States	Japan	Japan
3	7.8%	Japan	China	Germany
4	6.3%	Germany	Germany	China
5	3.1%	Korea	Italy	France
6	2.4%	Italy	France	Italy
7	2.4%	France	United Kingdom	United Kingdom
8	2.3%	Russia	Korea	Brazil
9	2.1%	Brazil	Canada	Russia
10	2.0%	United Kingdom	Spain	Korea

Figure 2.1: World's leading manufacturing nations – In 2013 China and the United States were the world's highest manufacturers, responsible for 40.4 per cent of world manufacturing (Meckstroth, 2015).

This situation is exacerbated by national and international rules that affect materials production and trade. Industrial nations such as China and the United States of America have subsidised raw materials industries to accommodate continuous supplies and low prices for economic success, while efficient use of these materials has received little consideration. An example of international and national rules that work in favour of unsustainable mining practices is the United States' *General Mining Act of 1872*. This legislation was originally mandated with a vision to foster settlement of new lands, it allowed for large subsidies for mining and to date has never been changed. In 2007 the *Hardrock Mining and Reclamation Act, 2007* was introduced to the US House of Representatives to limit the freedoms allowed in the outdated

General Mining Act of 1872 but this bill was not acted upon by the Senate and died. The act was again introduced in 2009 but dismissed in committee (H.R. 699. 111th Congress, 2009). Young and Sachs (1994) identified that such changes were impeded by principal beneficiaries of the outdated *General Mining Act of 1872*.

With millions of dollars to spend on campaign contributions and public relations campaigns, the large mining companies that are the law's principal beneficiaries have so far managed to convince U.S. legislators that changing the Act would be politically unwise. (Young and Sachs, 1994, p. 18).

This was substantiated when the National Mining Association (NMA) was given an opportunity to discuss these Acts with the House of Representatives. They stated that the royalty imposed by the proposed 2007 bill would have burdened US mining with the highest effective tax rate in the world (NMA, 2009, p. 3).

Outdated policies in tandem with large mining operations across the globe have encouraged production of virgin materials and, in effect, provided incentives to be wasteful. A fundamental characteristic of consumer behaviour is the ability to ignore the environmental cost. Residents of many first world countries rarely consider where the raw materials in their cars, sofas, or stereos came from, or how they were shaped into useful form. Few people ever recognise the consequences of constantly acquiring and discarding their increasingly plentiful and inexpensive consumer goods. The potentially high environmental costs of global practices raise the question, how do these global practices affect New Zealand?

2.3 The New Zealand scale

2.3.1 How does the world affect New Zealand?

The consumer behaviour observed worldwide following the industrial revolution has affected New Zealand consumer behaviour significantly and more so today as the nation relies heavily on internationally sourced goods. The structure of New Zealand's economy has changed considerably since 1972. Manufacturing has declined and services now make the biggest contribution to GDP (Statistics New Zealand, 2015a). Primary industries and goods production industries have significantly decreased during this period.

Figure 2.2: Contribution to gross domestic product. Statistics New Zealand, 2015a.

2.3.2 Goods-producing Industries

Goods-producing industries are all the manufacturing, construction, electricity, gas, water supply, and waste management industries. (Statistics New Zealand, 2015b). The biggest decline observed in the goods-producing industries was in the manufacturing industries. As shown in figure 2.2, in 1972, manufacturing industries were the largest contributors to the nation's GDP, but this has changed.

In the 1970s, trade and tariff barriers protected New Zealand manufacturers from foreign competition. In the mid-1980s, the country went through a host of market reforms that threw the economy wide open. As a result, manufacturing steadily declined as a proportion of New Zealand's GDP. Forty years ago, manufacturing made up 26 percent of GDP. In 2009, this industry made up 13 percent of GDP. (Statistics New Zealand, 2015b).

Figure 2.3 clearly shows the decline in a range of manufacturing industries between 1972 and 2009, with some, such as textiles etc., almost disappearing from the economy.

2.3.3 Primary industries

In this same period primary industries saw a similar decline. Primary industries include agriculture, fishing, forestry, and mining. (Statistics New Zealand, 2015b).

New Zealand has been promoted as a major world food exporter. Our statistics show that agriculture's relative contribution to GDP decreased significantly, from 10 percent in 1972 to 4 percent in 2009. However, this decline does not include any downstream effects in related industries such as dairy product manufacturing. Until the early 1980s, the New Zealand government focused on maximising agricultural production and farmers enjoyed large subsidies. Agriculture's contribution to GDP peaked in 1973 and 1980, boosted by soaring commodity prices and record sheep and beef exports. Things changed in 1985, when the government floated the dollar and began phasing out support for agriculture, including fertiliser subsidies and tax concessions. The agriculture industry's contribution to GDP has been generally declining since then, with the occasional rise. This industry is strongly affected by commodity prices, currency fluctuations, and weather-related events such as droughts. (Statistics New Zealand, 2015b).

With primary industries and manufacturing industries on the decline, the New Zealand market has come to rely heavily on imported goods from the global market. In 2012, seventy-two per cent of all imports into New Zealand consisted of manufactured goods from the international market (Statistics New Zealand, 2015b). Therefore the extractive and unsustainable practices of manufacturing nations throughout the globe directly influence the New Zealand market and may well be influencing consumer behaviour in the household. In response to the growing concerns regarding New Zealand's impact as a consumer nation, works by researchers such as Alcorn and Mithraratne and labelling systems in New Zealand, identified earlier in chapter one (sections 1.3 and 1.8), have been directed at understanding environmental impacts and how the country could minimise these. Many of these works focused on exploiting more renewable sources of energy, minimising materials use and promoting more efficient appliances and household practices, all in the interest of meeting emissions reduction targets. This is discussed in greater detail in the following section.

2.4 Target emissions

In early 2012 a global conservation organisation the WWF (World Wildlife Fund/World Wide Fund for Nature) released an environmental report named *Beyond Rio* (WWF, 2012), comparing global emissions. One of the key findings was that New Zealand's gross CO₂ emissions have risen by twenty per cent since 1992. WWF has played a role in holding governments to account, both globally and nationally (WWF, 2012). Their reporting

critically sheds light on government figures and how these measure up against the promises made over twenty years ago in the ratified agreement, the United Nations Framework Convention on Climate Change (UNFCCC). The twenty per cent increase in CO₂ emissions identified in this report substantiate government reporting, four years later, that identified that since 1990, New Zealand's gross emissions have increased twenty-three per cent, predominantly due to increased emissions from the energy and agriculture sectors (Ministry for the Environment, 2016a).

Even with the Emissions Trading Scheme, introduced in 2008 and then weakened in 2009 (WWF, 2012, p. 9), New Zealand's total emissions were projected to continue to rise by 2020 (WWF, 2012, p. 9). As a result of these ever increasing numbers, at a conference of parties to the Copenhagen Accord in 2009, New Zealand agreed to reduce emissions to between ten to twenty per cent below 1990 levels by 2020. (NZ Parliament, 2011). However, late in 2015 at the 2015 Paris agreement (Ministry for the Environment, 2016b), the reduction target was again changed, and due to a lack in progress and success in implementation of reduction policies the New Zealand government submitted an addendum to the original agreement.

As a result, New Zealand's current target is to reduce greenhouse gas emissions by thirty per cent below 2005 levels by 2030. This target is equivalent to eleven per cent below 1990 levels by 2030 (Ministry for the Environment, 2016b).

The New Zealand *Greenhouse Gas Inventory* report identifies that New Zealand's gross CO₂ equivalent emissions were just over sixty million tonnes (60,600,000 tonnes) for the year ending 1990 (Ministry for the Environment, 2016c). An eleven per cent reduction, below 1990 levels, sets the CO₂ equivalent emissions target, by 2030, at just under fifty-four million tonnes (53,934,000 tonnes).

The New Zealand *Greenhouse Gas Inventory* report also shows that the current¹ gross CO₂ equivalent emissions are just over eighty-one million tonnes (81,100,000 tonnes). In order to meet this target, based on current CO₂ equivalent emissions, New Zealand's total emissions must be reduced by approximately twenty-seven million tonnes (27,166,000 tonnes).

¹ The "Current" emissions value is defined as the gross CO₂ equivalent emissions reported by the Ministry for the Environment for the year ending 2014.

2.5 Increasing emissions: Where to measure behaviour?

With emissions increasing in the energy and agriculture sectors, an effective way to address the thesis question in accounting for the impact of behaviour may be to focus specifically on these sectors. The energy sector includes all emissions associated with energy consumption, including transport, electricity generation and residential and commercial use of all energies and fuels (Ministry for the Environment, 2016c). Data from WWF (2012), total CO₂ equivalent emissions in New Zealand as of 2014 (Ministry of the Environment, 2016c) discussed later in this thesis, and the reduction target changes made by the New Zealand government (NZ Parliament, 2011), all show that recent increases in emissions and targeted reductions are moving further away from any improvement. The increases in emissions in the energy sector suggest that in order to understand the effect of behaviour in a household, the manner in which household energies (all fuel sources, electricity, gas coal, etc.) are utilised, during day to day practices, may hold the answer to understanding these increased emissions. This may also shed light on whether or not behaviour in the use of household energy is playing a significant role, which aligns with the central focus of this thesis.

In order to understand day-to-day household emissions produced in the act of dwelling, instead of looking at the combined effects of furniture, appliances and interior fit-outs as posited earlier, the focus of the analysis phase will be the ownership and operation of household appliances. This is because increased emissions observed in reported figures have been predominantly linked with the energy sector and appliances are the aspect of the act of dwelling likely to have the largest effect on energy, as, unlike furniture or interior fit-outs, appliances have operational as well as embodied energy.

2.6 Summary of consumer behaviour: Global scale interaction

This chapter identifies that worldwide use of raw materials is increasing. While materials usage in developed nations may be levelling off, global use is still on the rise. Nations like New Zealand with a relatively small manufacturing sector encourage this global use by creating a demand for manufactured goods outsourced to other countries.

Consumer behaviour in New Zealand is heavily influenced by the international market due to the nation's reliance on imported manufactured goods, (comprising seventy-two per cent of the cost of all imports, including things like cars, trucks, trains and aircraft as well as fridges and dishwashers. Section 2.3.3).

Not being a manufacturing nation means that New Zealand could potentially make a reduction in its contribution to the global footprint of the planet. Many of the extractive practices of the world are not directly originating in New Zealand but are rather fostered by New Zealand's demand on the international market for manufactured goods.

Having established New Zealand's significant interdependence on energy intensive practices at the global scale, this chapter then scrutinised reported emissions figures to establish where emissions specific to the New Zealand scale have significantly increased. This investigation found that significant increases in emissions have been predominantly observed in the energy and agricultural sectors. In keeping with the focus of the thesis topic, this identified that the energy sector is the area in which household behaviour may be contributing to the increasing national emissions.

The final part of this chapter identified that establishing the effect of household choices, which specifically relates to the energy sector, is the most appropriate way to understand

household impact due to behaviour. For this reason, instead of looking at furniture, interior fit-outs and appliances, as initially proposed (chapter one, section 1.3), the central focus of this thesis is to measure the impact of behaviour by examining the day to day behavioural choices made of appliance ownership and operation.

2.7 The next step: Chapter three

To better understand consumer behaviour at the New Zealand scale, chapter three specifically looks at usage trends in New Zealand. To this end, chapter three looks into household emissions, recent electricity generation and consumption trends, and also long term consumption trends to better understand consumer behaviour in New Zealand and what this may potentially mean for the future and the reductions targets identified in this chapter.

Chapter three also scrutinises reported observations made by a household energy use study that looked into the manner in which houses across the country operate.

Chapter Three

Consumer Behaviour: National Scale Consumption

Had we started from there and done all these things then, the world would be a very different place right now. Achieving fair earth share living today is going to be a much harder task.

- Vale and Vale, 2013, p. 319.

3.1 Introduction: Understanding what is already measured

Detrimental environmental effects and emissions caused by behavioural choices are not unknown, a fact Robert and Brenda Vale have made frequently (Vale and Vale 2009a; 2009b; 2010; 2013). As shown above, Vale and Vale identify that achieving fair earth share living today is going to be much more difficult. This will be, in no small part, due to consumer behaviour and usage. In order to understand usage and consumption at the national scale, this chapter focuses on impact associated with electricity generation, specifically observing trends of usage. Having established New Zealand's reliance on imports for manufactured goods, this chapter specifically looks at the operational side of these manufactured goods. As identified in chapter two, the central focus of this thesis is to measure the impact of behaviour in households, specifically looking at appliances. Because most domestic appliances are manufactured overseas it follows that the main New Zealand-related effect will be from the

electricity used to operate such appliances, making it important to understand the emissions from New Zealand electricity generation.

As shown in figure 3.1, the Ministry of Business, Innovation and Employment reported that atmospheric CO₂-equivalent emissions from electricity generation dropped to seven and a half million tonnes in 2009 from just under ten million tonnes in 2008. This was twenty-three per cent of New Zealand's total CO₂-equivalent emissions of thirty-two million tonnes (net) in the energy sector. With the exception of minor drops in 2007, this was the first major drop since 2002, but electricity generation emissions since 1990 have consistently been responsible for approximately a fifth of total energy sector emissions in New Zealand as shown in figure 3.1.

In order to understand the potential for reduction in the New Zealand atmospheric CO₂ contribution from electricity generation, this chapter looks back through recent history. The goal is to identify and compare four different periods over the past thirty-five years. Each has been selected for its characteristic mix of electricity generation sources.

The first period is the year ending 1980 when ninety-one per cent of the electricity generated in New Zealand was generated using renewable sources. This is the closest New Zealand electricity has ever been to being completely renewable (Ministry of Business, Innovation and Employment 2015a). With total CO₂-equivalent emissions of just under seventeen million tonnes (net) for the entire country (this is twenty-six per cent less than the year ending 1990),

this 1980 footprint is a good example to follow in order to try to meet New Zealand's targeted emission reductions by the year 2030.

The second period is the year ending 1990, the year documented in the Kyoto Protocol that aimed to reduce total greenhouse gas emissions to pre-1990 levels by 2012 (United Nations, 1998, pp. 19-20). New Zealand's agreement at a conference of parties to the Copenhagen Accord in 2009 was based on these emissions targets set in the Kyoto Protocol (NZ Parliament, 2011). The new targets, set in 2015, discussed earlier, are also based on the original Kyoto protocol targets.

The third period is the year ending 2007 which was investigated in a study by Rule, Worth and Boyle in 2009. This study of electricity generation looked at the 2007 electricity mix and the embodied energy coefficients of each electricity generation source. It showed that New Zealand still generated a significant amount of electricity from renewable sources, but not as much as in 1980. Rule, Worth and Boyle's study in 2009 also began to raise the question, would a solely renewable electricity generating mix be enough to meet the country's total electricity requirements? The fourth period investigates the electricity mix of today, based on the most recent energy data available (from data published by the Ministry of Business, Innovation and Employment for the year ending 2014). The aim of comparing these four periods is to identify the limitations, if any, of a solely renewable electricity mix and to explore if a move to a solely renewable electricity mix in the future can provide a meaningful reduction in CO₂ emissions. A renewable-only electricity supply could be assumed to reduce the impact of household behaviour in regard to the operation of appliances. The final part of this chapter investigates current household energy usage patterns based on the ten-year Household Energy End-use Project (HEEP) study.

3.2 Electricity and its generation

A recent life cycle analysis of common heating appliances (Bakshi et al., 2013) presented the total weighted embodied energy (i.e. the energy used to make electricity) resulting from the current electricity generation mix in New Zealand. These figures were based on 2007 electricity mix data and embodied energy coefficients presented by Rule, Worth and Boyle (2009). This thesis uses these embodied energy figures for each source of electricity. The analysis indicates that nearly all the embodied energy of the electricity mix from the year

ending 2007 was from the non-renewable sources of electricity generation, although non-renewable electricity generation sources were not the highest electricity producing sources.

Source of electricity	% of electricity mix	Embodied energy kJ/kWh	Weighted embodied energy kJ/kWh
Hydro (pp. 6406)	55.2	55	3036
Geothermal (pp. 6406)	7.6	94.6	719
Wind (pp. 6406)	3.2	70.2	225
Gas (pp. 6412)	21.8	7608	165854
Coal (pp. 6412)	12.2	3714	45311
Total	100		2151KJ/kWh (approx. 0.6kWh/kWh)

Figure 3.2: Electricity mix as presented by Bakshi et al. (2013, p. 340), from Rule, Worth and Boyle (2009, pp. 6406-6412).

Figure 3.2 depicts these electricity mix data. The embodied energy coefficients of the non-renewable sources of electricity generation, calculated for New Zealand, were established by Rule, Worth and Boyle (2009) using data originally sourced from Alcorn (2003, p. 19). The embodied energy coefficient for natural gas is 7608 kJ/kWh (193.6g CO₂/kWh) and 3714 kJ/kWh (325.7g CO₂/kWh) for coal. (Alcorn 2003, p. 19). These coefficients are based on data for the raw materials of gas and coal but only to the power station gate (Rule, Worth and Boyle 2009, p. 6412). Alcorn's figures here do not consider these fuels when used for electricity generation. Therefore, figures from the Ministry of Business, Innovation and Employment (2016b, p. 6) are used, which take into account how the fuels are burned to generate electricity. These MBIE CO₂ equivalent emissions for coal fired electricity generation (720g CO₂/kWh) and gas fired electricity generation (420g CO₂/kWh) are used as these are more accurate coefficients.

Renewable sources of electricity generation also have an embodied energy and CO₂ cost. Rule, Worth and Boyle (2009) conducted a study to specifically identify the embodied energy coefficients of renewable energy generation. This study is the most recent analysis of renewable energy generation sources specific to the New Zealand electricity grid. Their study identified that electricity sourced from the wind has an embodied energy of 70.2 kJ/kWh (3.0g CO₂/kWh), hydroelectricity has 55.0 kJ/kWh (4.6g CO₂/kWh), and geothermal electricity has

94.6 kJ/kWh (120g CO₂/kWh) (Rule, Worth and Boyle 2009, p. 6406). Due to the much larger carbon dioxide emissions per kWh of the carbon-based non-renewable sources, the data confirm that non-renewable electricity generation is the largest ecological liability, as a result of the embodied energy and emissions required to produce electricity from the non-renewable fuels, gas and coal. This raises the question of how significant is the embodied energy of non-renewable electricity generation in comparison with renewable sources, given that renewable sources are used more. Rule, Worth and Boyle (2009) used electricity mix data presented by the Ministry of Business, Innovation and Employment in the annual report from 2007 (2015a).

These data are presented graphically in figure 3.3 to demonstrate what the 2007 electricity mix, the mix of renewable and non-renewable sources in the upper bar of the chart, looks like in regard to the embodied energy used by the various renewable and non-renewable sources presented in the lower bar. This “energy return on energy invested” chart maps how much of the total embodied energy is caused (energy invested) by the energy returns (electricity generation) from each source. Once this information is mapped in this manner, the situation is more evident.

Figure 3.3 shows that just over ninety-eight per cent of the embodied energy of the New Zealand electricity mix in 2007 came from the non-renewable sources (i.e. gas and coal). These were responsible for only thirty-four per cent of the electricity generated in the total electricity mix. In 2007 sixty-six per cent of the electricity generated in New Zealand was generated from renewable sources but it was responsible for less than two per cent of the total embodied energy

of the electricity. The electricity mix from 1980, 1990 and that for 2014 (i.e. today's mix²) are also mapped in a similar way below to show the energy return on energy invested. The 1990 mix is mapped because the current emission reduction goals are based on a target ten to twenty per cent less than 1990 (see Section 3.2.2). Looking at the embodied energy of a 1980 mix (when the percentage of renewables was highest) will determine if electricity generation energy investments and returns have always been so environmentally unviable.

The 1980 electricity mix is shown in figure 3.4 based on data from the annual report from the Ministry of Business, Innovation and Employment (2015a).

The 1980 electricity mix indicates one of the more surprising facts about the ecological cost of electricity generation in New Zealand. In 1980 the electricity mix was ninety-one per cent renewable and, as shown in figure 3.4, the nine per cent of the electricity being generated in New Zealand from non-renewable sources was responsible for just under ninety-two per cent of the embodied energy. The varying availability of renewables throughout the year could have played a role in the need for the nine per cent of non-renewable electricity generation, this merits further research into how each energy source served the electricity grid.

While the electricity generation data from 1980 show a situation with a low use of non-renewable resources, the 2007 mix identified earlier in figure 3.3 indicates that as time has progressed since 1980, energy demand requirements have resulted in an increase in the use of

² Current electricity mix is based on 2014 data. While 2015 data is projected, this has not been validated and cannot be until the entire year's readings can be measured. See the supplementary information in appendix D for calculation tables.

non-renewable sources for electricity generation. The current mix (shown in figure 3.5) seven years later, shows a similar result to that seen in the 2007 mix.

The 2014 electricity mix generates eighty per cent of its electricity from renewable sources, this is a significant increase on the sixty-six per cent produced in 2007. This is the highest annual share of electricity generation from renewables since 1996 (Ministry of Business, Innovation and Employment 2015c). This number is significant as it suggests that since 1996 technology has evolved. New Zealand electricity generation is apparently more efficient in terms of usage of non-renewable sources as more electricity is being sourced from renewable resources. However, the 1990 mix suggests that little has changed. Figures 3.5 and 3.6 show that the proportions of electricity currently generated from renewables and non-renewables are approximately the same as they were in 1990.

3.3 Electricity usage trends

The study by Rule, Worth and Boyle in 2009 identified that New Zealand generates a significant amount of electricity from renewable sources, however, there is still a heavy reliance (in terms of embodied energy in particular) on gas and coal powered electricity generation. Rule, Worth and Boyle also identified various international endeavours to invest heavily in renewable energy sources in order to meet the electricity requirements of their populations and reduce their contribution to global greenhouse gas emissions. New Zealand is part of this global effort as identified earlier by New Zealand's agreement to reduce emissions to between ten and twenty per cent below the 1990 levels by 2020.

The total electricity generated and the electricity consumed vary due to annual losses in transmission and distribution of the electricity. As reported by the New Zealand Electricity Authority, there are four types of losses within a network (Electricity Authority NZ, 2015):

1. Technical losses - the difference between energy injected into a network and energy delivered to points of connection. These losses can result from the inevitable physical loss of electricity in networks.
2. Non-technical losses - the difference between the volume of energy conveyed at points of connection and the volume of energy reported as conveyed at the same points of connection. These losses can result from theft, metering errors and data handling errors.
3. Reconciliation losses - the difference between reported energy injected into a network and the reported energy extracted from the network. Reconciliation loss is the combination of technical and non-technical loss.
4. Unaccounted for electricity (UFE) - this is calculated from the difference between reported energy injected into a network and the reported energy extracted from the network after it has been adjusted for losses.

Electricity generation and consumption figures from the “energy return on energy invested” studies in figures 3.3 to 3.6 are plotted in figure 3.7. The shifts in energy consumption data from 1980, 1990, 2007 and then 2014, seem to depict conflicting patterns of consumption and generation, initially showing an increase from 1980 to 2007, and then a slight decrease to 2014.

Figure 3.7: Electricity generation and consumption figures, graphed from the above-mentioned “energy return on energy invested” studies (figures 3.3 to 3.6).

In order to assess this shift in electricity consumption (from 2007 to 2014), it is important first to understand the trends occurring in the data collected between these years. To achieve this, all electricity consumption graphs are mapped below with trend lines to see how, or if, consumption over time has changed. Trend lines provide a good indication of what to expect in the future as they show a statistical trend occurring in a graph (Merriam Webster Dictionary, 2016). The trend line used to depict the electricity consumption trend from 2007 to 2014 (depicted in figure 3.8) is a linear trend line. In the graph in figure 3.8, the gigawatt hours of electricity consumed are plotted annually to depict the change in usage over time. This data suggests there is no significant trend in energy consumption observed here.

Figure 3.8: Total electricity consumption trend 2007 -2014 (data sourced from the Ministry of Business, Innovation and Employment, 2015a).

Even though the trend from 2007 to 2014 looks like a slight downward trend in annual electricity consumption, the R-squared value of almost zero identifies that this trend line is not reliable.

An R-squared (or correlation coefficient) value identifies the predictive ability of the data plotted in a graph. An R-squared value of one means that real data and the predictive ability of the data coincide (Pries and Dunnigan, 2015, p. 268). This graph, as a result, cannot support the argument that there has been a downward shift in consumption. More data points (annual consumption readings) are likely to increase the reliability.

The trend line in figure 3.9, which covers electricity consumption over twenty years shows a higher R-squared value. As a result, this longer-term observed electricity consumption trend may be considered more reliable than the observed electricity consumption trend from 2007 to 2014 (figure 3.8). This trend analysis clarifies the results observed in figure 3.8. Observing electricity consumption over shorter periods often produces trend lines that are not as reliable. While figure 3.8 could be used to argue a downward shift in consumption behaviour, this apparent decrease in (or flattening out of) consumption is not a reliable representation due to its short-term nature. Depicted in figure 3.9, the electricity consumption trend line that suggests a good fit with the data points, based on observed consumption over two decades, indicates a more troubling trend in electricity consumption. Figures 3.8 and 3.9 suggest that, while there have been short periods in which consumption was seemingly decreasing, the overall long-term trend of electricity consumption in New Zealand has been steadily increasing. A longer term study, dating back to 1980 depicted in figure 3.10 substantiates this. As seen by the two

smaller dashed trend lines in figure 3.10, there are short periods in which electricity consumption levels out. During this time there also appears to be an increase in the non-renewable sources that are being used.

Figure 3.10: Long-term electricity consumption patterns, with short periods in which consumption seems to decrease or flatten out (data sourced from the Ministry of Business, Innovation and Employment, 2015a).

In order to rule out possible periods of economic downturn that could be responsible for short term flat trends, figure 3.10 was compared to the Gross Domestic Product (GDP) report for New Zealand. Looking at GDP data, sourced from the OECD database (OECD, 2017), none of the short term flat trends (observed in figure 3.10) align with periods of economic downturn, the GDP has consistently increased since 1990 as shown below.

Figure 3.11: Gross domestic product (GDP) Total, US dollars/capita, 1980 – 2015. The OECD total (per capita) is shown in black and the New Zealand (per capita) data in red (OECD, 2017).

3.4 Jevons' Paradox

Electricity is the only viable energy source for a large array of appliances. Supplying energy to the most basic devices including computers, refrigerators, lawnmowers and nowadays, even cars, electricity is becoming the true "wealth of nations" (Observ'ER, 2013). Electricity generation today has become what coal was in the nineteenth century, as discussed below.

Jevons' paradox of 1865 states that the efficient use of a resource will tend to prompt increased consumption (Jevons, 1865). It is possibly one of the most appropriate theoretical arguments to discuss regarding the trends observed in this chapter so far. However whether or not these trends do in fact suggest Jevons' observations are in effect, is yet to be determined. In order to investigate this, it is essential to first examine what Jevons' paradox is, what he said and the motivation behind it.

Jevons' 460-page argument presents his concern not only for England's material and intellectual prosperity but also for posterity. This prompts his question of the coal supply's duration. Since coal is the fuel for progress, and it will eventually run out, his answer is pessimistically bittersweet (Alcott, 2005, p. 11). Jevons' paradoxical observation was that coal-efficiency heightens coal consumption.

Alcott identifies that this theoretical argument relied on the concepts of profitability, new inventions and uses, as well as consumer behaviour. Alcott goes on to summarise Jevons' theory regarding the coal question and the paradox of efficiency and usage:

Jevons insisted that "...the quantity of coal existing is a less important point in this question than the rate at which our consumption increases, and the natural laws which govern that consumption (pp. 25, 34–36). What determines this all-important rate of consumption's increase? Always based on assumptions about coal quality, mine depth, and mining costs (pp. 88–89, 132, 156, 230–32, 274, Ch. IV), three factors were population growth (pp. vi, 9–10, 194–200, 275, 457), newly found or invented applications (pp. 141–142, 152–53, 176, 196, 457–458, Ch. VI), and our wish to consume (p. 25, Ch. IX). But 'discovery' was constantly rendering coal 'a more and more efficient agent...' (p. 8; also 136, 387–88). The bone of contention was whether this raises, or lowers, total consumption. Jevons' dissenting opinion was that it is the

very economy of its use, which leads to its extensive consumption (p. 141). Due to invention and improvement “...the economy of coal in manufactures” advanced constantly (pp. 8, 152), but “It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth....Every...improvement of the engine, when effected, does but accelerate anew the consumption of coal” (pp. 140, 152–53). (Alcott, 2005, p. 11).

Presented here by Alcott, the inherent correlation of usage and efficiency argued by Jevons a hundred and fifty years ago raises the question, will the effect of a renewable mix for electricity generation be inconsequential due to consumption inevitably increasing, whether it be due to population growth, new inventions or our wish to consume? Specifically, in spite of increasing the percentage of renewables in the electricity generation mix, will the country’s total carbon emissions continue to rise?

In an attempt to answer this question, in figure 3.11, current electricity consumption trends are graphed with changes in electricity generation from renewable sources. Graphing electricity consumption against the percentage of electricity generated from renewable sources identifies two opposing trend lines.

As shown in figure 3.11, though electricity consumption is constantly increasing (since 1980) regardless of the sources that constitute the electricity mix, the rate of this increasing consumption has been decreasing since 2007. The percentage of electricity generated from renewable sources has also increased in this time frame although it is not yet at the level it

reached in 1980. If we also consider that the New Zealand population increased from 3.8 million people in the year 2000 to 4.5 million people today (Statistics New Zealand, 2015c), this suggests that consumption per capita is decreasing slightly, as shown in figure 3.13.

Even though figure 3.13 identifies that usage per capita is decreasing, the fact that total usage is increasing suggests some aspects of Jevons' paradox are in effect today, albeit due to population increases.

3.5 Technology-only solutions to meet targets: Going solely renewable

What do these figures mean for tomorrow? Can current usage trends allow for a solely renewable electricity mix in the future to provide a significant reduction in emissions? In order to answer this question, it is first important to ascertain future requirements. The current emission reduction goal set by New Zealand is aiming for a CO₂ equivalent reduction by the year 2030 of at least eleven per cent less than what it was in 1990 (Ministry for the Environment, 2016b). In order to consider the extent to which carbon emissions can be reduced, this research will consider projected electricity generation requirements for the year 2020 based on observed trends in electricity generation (figure 3.14). The 2020 target has been retained here because a thirteen-year projection, to 2030 is likely to yield less accurate electricity consumption figures than a three-year projection. A completely renewable mix, ten years before the target will also identify the immediate reductions that can hypothetically be achieved in the environmental impact of electricity.

Figure 3.14 depicts the predicted electricity generation requirements as a continuation of trends in electricity generation dating back to 1994. Generation and consumption trends have seen a significant shift since the turn of the century, first rising quite rapidly and then declining slightly. In order to account for this shifting behaviour in electricity generation, the data points plotted in figure 3.14 use a power trend line. Unlike the linear trend lines used earlier, the power trend line is a curved line that is best used with data sets that compare measurements that increase at a specific rate. It can account for patterns of change over time (Kotu and Deshpande 2014, p. 182). This is an important step in predicting future generation requirements.

While a linear trend line will depict the direction in which trends are sloping with regard to observed data, a power trend line will follow changing trends based on currently observed trends of electricity generation. As a result figure 3.14 suggests that the electricity generation requirement for 2020 is likely to be around 43,800 GWh.

Based on this predicted electricity generation figure it is now possible to compare the total embodied energy of electricity in New Zealand in 1980, 2007 and 2014 (current electricity mix) with a future 100 per cent renewable only mix in 2020. Unlike the earlier embodied energy study of the annual electricity mix data (section 3.2), with its focus solely on the embodied energy of the generating mix, the "total emissions of electricity" expressed here in tonnes of CO₂ represent the emissions for the GWh of electricity generated for the year in question, depending on the fuels used.

	Total emissions of NZ Electricity Generation (CO₂ in Tonnes)	Percentage of emissions that renewable sources are responsible for	Percentage of total electricity generated by renewables
1980	1,379,432	32%	91%
1990	3,150,344	15%	81%
Rule, Worth and Boyle (2009) 2007	7,391,061	8%	66%
Current (2014)	5,299,947	22%	80%
Future (2020) if 100% renewable²	1,369,662	100%	100%

Figure 3.15: Total CO₂ emissions from New Zealand electricity.

Figure 3.15 identifies the CO₂ equivalent emissions resulting from electricity generated in New Zealand in 1980, 1990, 2007, 2014 and 2020. The important aspect to note about the data presented in this table is that it is now possible to see the emission cost for the type of electricity generation mix used and also how more renewable electricity sources can create a significantly decreased emissions footprint, even less than what it was thirty-five years ago.

Even though in 1980 renewable electricity sources were responsible for thirty-two per cent of CO₂ emissions for New Zealand electricity, it is important to remember that then nearly all the electricity generated (ninety-one per cent) came from these renewable sources.

In 2007 New Zealand electricity was responsible for 7.4 million tonnes of CO₂ equivalent emissions, which is approaching two tonnes per person. This is not at all surprising as two factors played a role in this footprint. First, the electricity generation requirement was almost two times more than electricity generation in 1980, while the population had increased by a third since 1980, and second, the electricity mix in 2007 was only sixty-six per cent renewable (figure 3.3).

Considering that about eighty per cent of the current electricity mix is sourced from renewable sources (figure 3.5) then today's two million tonne reduction, from the 2007 figure makes sense in spite of the counter-effect of rising demand. These figures are presented in figure 3.16.

Figure 3.16 depicts the total CO₂ equivalent emissions of New Zealand electricity. This graph identifies the total CO₂ emissions, what portions of these emissions come from renewable and non-renewable sources, and also the gigawatt hours of electricity generated for each year presented here. Putting all of this information together in this way reveals an important detail. CO₂ equivalent emissions of a one hundred per cent renewable mix for New Zealand electricity in 2020 can go far below the current electricity footprint, the CO₂ emissions can be the same as the total footprint of electricity in New Zealand in 1980. This is particularly noteworthy as the projected electricity generation in 2020 is roughly twice the electricity generated in 1980 as shown in figure 3.16.

These figures can now be used to determine if a solely renewable electricity mix can provide a meaningful reduction in New Zealand's gross CO₂ equivalent emissions.

In order to conduct CO₂ equivalent emissions analyses, this study uses the figures published by the Ministry for the Environment, in the New Zealand *Greenhouse Gas Inventory* report (Ministry for the Environment, 2016c). New Zealand's *Greenhouse Gas Inventory* is an annual report of all human-induced emissions and removals of greenhouse gases in New Zealand. The inventory is produced each year as part of New Zealand's obligations under the United Nations

Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Ministry for the Environment, 2016b).

The CO₂ emissions in New Zealand, in this report, are reported to the end of 2014. This is because the international reporting guidelines govern what the inventory covers and when it is submitted. The inventory year is fifteen months behind the current calendar year to give time for countries to collect and process the inventory data and prepare the submission. The latest inventory, published in May 2016, contains data from 1990 to 2014 inclusively. All developed countries report using the same international guidelines (Ministry for the Environment, 2016b).

The New Zealand *Greenhouse Gas Inventory* identifies New Zealand's gross CO₂ equivalent emissions for the year ending 2014 (Ministry for the Environment, 2016c). Therefore the definition of current emissions for New Zealand, for the purposes of this study, will be represented by this 2014 figure of just over eighty million tonnes (81,100,000 tonnes), as shown in figure 3.17.

Figure 3.17 identifies by how much the total annual CO₂ equivalent emissions (all emissions, not just those related to energy or electricity) are reduced for New Zealand. By incorporating a solely renewable electricity mix, a five per cent reduction of New Zealand's current total CO₂ emissions can be achieved. As shown in figure 3.17, simply incorporating a renewable mix does not solve the problem, but it moves closer to the current emissions reduction target set in

2015 of an eleven per cent reduction in 1990 emissions, as represented by the horizontal dotted line on figure 3.17.

A shift in the manner in which electricity is generated can reduce New Zealand's overall emissions footprint, this shift does not require a change in behaviour or even a reduction in current levels of consumption. The reduced footprint is achieved in spite of the generation requirements that are still increasing as shown in the trend line in figure 3.14.

Figure 3.17 suggests that large-scale technology-only solutions such as a solely renewable electricity mix will not be enough to achieve the targeted emissions reduction identified during the 2015 Paris agreement (Ministry for the Environment, 2016b). This raises the question whether it is logical to consider, rather than more sustainable means of electricity generation at the large scale, more sustainable means of living by making changes in behaviour at the small scale, if possible without sacrificing "quality of life", however that might be defined. What is not known is whether such behavioural changes can make any meaningful difference in emissions, by reducing consumption, because the existing scale of these behaviour-related emissions is not known.

3.6 HEEP, observing New Zealand household Behaviour

The consideration of the effect of behaviour is important because the New Zealand residential sector is responsible for approximately forty per cent of all the electricity consumed in New Zealand (Ministry of Business, Innovation and Employment, 2016). Even with a 100 per cent renewable electricity mix, this is particularly important if the efficient use of a resource will tend to prompt increased consumption as theorised by Jevons' paradox presented earlier.

Figure 3.18 shows that total electricity consumption has significantly increased since 1974³ in comparison to the electricity consumption of the residential sector which was nearly 50 per cent of the total consumption in 1974 but only about 25 per cent by 2014, in spite of a slight increase. However, the residential sector is still an important area in which demand reductions may be possible, based on a change in individual decisions and personal behaviour. As a result,

³ All data trends are based on available open source information. This is limited to Ministry of Business, Innovation and Employment data that goes as far back as 1974.

it may be useful to understand electricity usage in the New Zealand residential sector and how behaviour may affect this.

To this end, the data collected by the Household Energy End-Use Project (HEEP study) is examined. The HEEP study was a long-term project with the objective of measuring and modelling the way energy is used in New Zealand dwellings (BRANZ, 2013). The data collected for the duration of the HEEP study is a valuable resource to understand how householders' behaviour in New Zealand dwellings affects electricity consumption. The HEEP study methodology utilised physical building and appliance characteristics as well as socio-demographic factors to describe the energy consumption patterns and some of the energy services. This methodology was used to understand current and future national household energy requirements and as a tool to evaluate the implications of building and appliance performance changes (Isaacs, Camilleri, and BRANZ, 2010).

The study comprised a detailed data collection period from 1999 to 2005 looking at three hundred and ninety-four houses throughout New Zealand⁴. The sample included dwellings from large and small cities, urban and rural areas and both the North and South Islands, from Kaikohe to Invercargill (BRANZ, 2013). As a result, the data can be considered a very good dataset of detailed energy consumption of households in New Zealand. In order to understand

⁴ The usage study is based on HEEP data that looked at just under 400 separate houses and not apartments or inner-city dwellings.

varying energy usage throughout New Zealand, the HEEP study plotted total energy usage in the country (figure 3.19). This identified the range of household energy consumption. In this graph, the percentage of residential energy consumption is plotted together with the number of houses responsible for this consumption.

The graph incorporates a series of reference lines to depict the percentage of houses (identified in the graph as ‘Energy’) and the percentage of total residential energy consumption they are responsible for (identified as the ‘Cumulative Energy’).

Using this graph the HEEP study identified the bottom and top twenty per cent of users (figure 3.20). The top twenty per cent of households use more than 14,450 kWh a year, and these households account for thirty-six per cent of the energy used in all households. Conversely, the bottom twenty per cent (eighty per cent on the Y-axis in figure 3.19) of households use less than 6,940 kWh a year, but they account for only nine per cent of the total household energy use (Isaacs, Camilleri, and BRANZ, 2010, p. 10).

Fuel	Bottom 20%		Top 20%		Ratio Top: Bottom
	Use under:	% of energy	Use over:	% of energy	
Electricity	4,860 kWh/yr	10%	10,380 kWh/yr	35%	2.1
Gas	2,580 kWh/yr	5%	9,900 kWh/yr	34%	3.8
Solid fuel heating	450 kWh/yr	1%	5,740 kWh/yr	57%	12.8
LPG heating	180 kWh/yr	3%	1,110 kWh/yr	50%	6.2
All fuels	6,940 kWh/yr	9%	14,450 kWh/yr	36%	2.1

Figure 3.20: Energy use distribution (Isaacs, Camilleri, and BRANZ, 2010, p. 10).

Figure 3.20 provides information on the highest and lowest twenty per cent for all fuels and also broken down by the type of fuel; electricity, gas, LPG and solid fuel.

The total and the individual fuels demonstrate skewed distributions, regardless of fuel type (Isaacs, Camilleri, and BRANZ, 2010, p. 10). This essentially means that high users, whilst comprising only a small number of houses, are responsible for a high proportion of the nation's residential energy consumption.

Energy Use Distribution (all fuels)			
	kWh/yr	Houses	Residential Energy
Low Users	0 - 4000	5%	2%
	4000 - 8000	28%	15%
	8000 - 12000	33%	31%
	12000 - 16000	20%	24%
High Energy Users	16000 - 20000	6%	10%
	20000 - 24000	3%	7%
	24000 - 28000	3%	5%
	28000- 32000	1%	2%
	32000 +	1%	4%

Figure 3.21: Energy use distribution breakdown. Tabulated based on HEEP data (Isaacs, Camilleri, and BRANZ, 2010, p. 10).

Figure 3.21 depicts what the overall energy use distribution looks like. The energy distribution breakdown table (figure 3.21) identifies the percentage of houses that use a particular range of energy in terms of kWh per year. Based on the HEEP study data, this table identifies the low users and the high users more explicitly than simply identifying the top and bottom twenty percentiles. Figure 3.21 identifies that higher users, approximately fourteen per cent of houses using from 16,000kWh per year upwards, are responsible for twenty-eight per cent of the total residential consumption.

Figure 3.21 also identifies that low users, only using up to 8000 kWh/year (only half of the high users' energy consumption) account for thirty-three per cent of houses and they use only seventeen per cent of the total residential consumption. Because the high and low users identified in figure 3.21 are considered in terms of all the fuels combined, it is now important to distinguish the use distribution in houses that use electricity only and no other fuels.

Figure 3.22 shows that the 'electricity-only' use distribution for all-electric houses has a similar spread to the 'all fuels' energy use distribution in figure 3.21. However, figure 3.22 also identifies that the highest user group of all-electric households use far fewer kilowatt hours (21,000+ kWh per year) than the highest all fuels user group, who use 32,000+ kilowatt hours per year (figure 3.21). The question remains, what is the cause of such a high variance between all-electric and all fuels users?

The HEEP study identifies that there is no statistically valid variation in energy use as a result of household income or occupancy. Instead, the dwelling size is one of the main factors that plays a role in the varying energy use, specifically illustrating that bigger houses have higher usage. The only other factor that was found to play a role in varied usage was life stage (Isaacs, Camilleri, and BRANZ, 2010. Appendix 2, pp. 119-121, 150).

The HEEP final report, published in 2010, graphed the results of varied dwelling sizes against the energy use of high, medium and low users over the ten-year HEEP data collection period, as shown in figure 3.23 (Isaacs, Camilleri, and BRANZ, 2010, p. 151).

Figure 3.23: Energy use variation based on dwelling size. As depicted in Isaacs, Camilleri, and BRANZ, 2010, p. 15.

Figure 3.23 identifies that the percentage of higher users increases with the dwelling size - big users tend to live in big houses. Tabulated in figure 3.24, the ‘all fuels’ energy use variation, based on dwelling size, is identified in terms of kWh consumed annually.

Sq Metres	Mean kWh	Median kWh	Minimum kWh	Maximum kWh
100 sq metres or less	9373	8076	2698	27585
101-150 sq metres	11467	10620	2889	44868
151-200 sq metres	13399	12147	4919	30968
201 or more sq metres	15349	13778	5782	28415

Figure 3.24: Mean, median, minimum and maximum ‘all fuels’ energy use variation based on dwelling size (Camilleri, and BRANZ, 2010, p. 150).

The HEEP study identified that this table and graph (figures 3.23 and 3.24) reflect the tendency for larger dwellings to use gas or to have multiple means of heating hot water. To understand this energy consumption and how it may differ from ‘electricity-only’ consumption, energy consumption by end use needed to be further explored. The HEEP breakdown of New Zealand household average ‘all fuels’ energy consumption by end-use is shown in figure 3.25. This graph identifies that the largest portion is space heating at thirty-four per cent, then hot water at twenty-nine per cent, and refrigeration, other appliances, lighting, and range at around ten per cent each. For ‘all fuels’ households the largest areas of energy use are space heating and water heating.

Figure 3.26 identifies an interesting difference in average 'electricity-only' end-use. 'Electricity-only' end-use, which represents houses with all-electric fuel sources, suggests that most appliance categories in all-electric houses have equal electricity use with the exception of hot water heating. Figures 3.25 and 3.26 show the national average energy end-use for all fuels and all-electric households respectively.

Figure 3.26 suggests that using electricity-only means of space heating lowers space heating energy use, at least as a percentage of total use. This could be the result of more energy efficient appliances that use only electricity, a theory substantiated by Bakshi et al. (2013) which identified that electrical technologies such as heat pumps can provide the same amount of heat

as apparently simpler woodburners but with much lower environmental impact, due to the heat pump's coefficient of performance (Bakshi et al, 2013, p. 342). Conversely, this could also mean that dwellings that are heated using 'all fuels' are heated more frequently with a higher usage, as would be observed in a dwelling that has gas central heating that heats every space.

The second theory is also supported by the data collected by the ten-year HEEP study which suggests higher energy users use gas or mixed means of space heating (Isaacs, Camilleri, and BRANZ, 2010, p. 150). As a result, one of the main conclusions that can be made from this study is that these high users might be able significantly to reduce their energy use by using energy efficient, "electricity-only," appliances for space heating. However, the HEEP data do not show exactly how energy consumption variation in these appliance categories differs for high and low users and thus what specific usage could be changed to decrease total consumption.

3.7 Theorised "*hidden emissions*"

Household behaviour in appliance ownership has a potential to affect appliance number. These can be dictated by personal preference or the size of the house. While appliance categories⁵ such as *space heating* are likely to be spatially related, increasing as the spaces that need to be heated increase in size and/or number, appliance categories such as *entertainment* or *general small portable appliances* can be personally related. At least some of these personally related appliance categories would theoretically have the same usage in high or low user households of the same size in terms of number of household members, as the number of people using the appliance should not increase or decrease. For example, one family of four using one hair-dryer for twenty minutes each a day would not increase their usage if they had four hair-dryers, because there would be the same number of users and the same quantity of wet hair, it would just mean that hair could be dried simultaneously rather than consecutively. On the other hand, a household with four music players could have four people listening to different music simultaneously.

While the operational energy requirement may remain the same for 'personally related' appliance categories like the hair-dryer, particularly with regard to house size, there could well

⁵ Appliance categories are defined in chapter six, these are established based on usage and the definition of appliances identified earlier in chapter two.

be a greater increase in embodied CO₂ emissions resulting from the number of appliances in a dwelling. For instance, four hair-dryers in a large four-bathroom dwelling with four occupants will still only dry four heads for twenty minutes each a day. The operation of the hair-dryers has not increased. However, the perceived convenience of having a hair-dryer in each bathroom has resulted in a greater embodied energy of this particular appliance in the dwelling due simply to the increase in the number of dryers in the four-bathroom dwelling. This indicates we may no longer be paying for convenience solely with money to buy the appliances, rather it seems we may be paying for convenience with increased *hidden emissions*, in this case, the emissions associated with the manufacture and shipping of three additional hair-dryers.

The environmental report discussed earlier in this paper, *Beyond Rio* (WWF, 2012), identifies that New Zealand's gross CO₂ emissions have risen by twenty per cent since 1992, due to increased emissions from various sectors including the energy sector. The question of appliance number, identified here, suggests that there may be additional *hidden emissions* which result from the embodied energy of the additional number of appliances, which may not be tracked by the existing emissions statistics, given that many of these appliances are imported, not made in New Zealand, as identified earlier. This suggests that the New Zealand residential sector's energy use as a result of appliance ownership could have a greater effect on total worldwide emissions than is currently observed in the data from the HEEP study or the reported data in the *Beyond Rio* report.

The question of the possible significance of appliance number suggests the presence of *hidden emissions* and makes it possible to theorise as follows:

The number of appliances is increasing New Zealand's total CO₂ emissions due to the increased embodied energy of an appliance category (simply due to the fact that there is a greater number of the appliance in a dwelling), whilst the operational energy is not increasing as much for the appliance category in question.

These theorised *hidden emissions* identify an important problem in current CO₂ data reporting. What is the overall effect of having all of these appliances, given that appliances may be quite energy and carbon intensive to manufacture? This would apply to ownership of everything from mobile phones to whiteware goods. Are we stacking up an invisible carbon debt that we do not think exists? This builds on studies such as 'The Ampere Strikes Back' (Goodyer, 2012),

which looked at operational energy of entertainment appliances but not their embodied energy. Because the embodied energy values will not be captured in the reported New Zealand domestic sector electricity demand data it is not possible to see how current appliance ownership (not simply usage) affects the total carbon emissions of New Zealanders, including those emissions which may be incurred in other countries. Given that manufacturing nations such as the United States and China have more carbon-intensive electricity generation than New Zealand (IPCC, 2016, p. 194), it is possible that the effect of the carbon emissions of imported appliances could be significant. This is because manufacturing emissions, counted in and allocated to manufacturing nations, are never added to the country of consumption. Doing so would paint a clearer picture of the emissions for which consumer nations are responsible. To avoid "double counting" emissions should also be subtracted from the country of manufacture. This sort of accounting could change the possible emissions balance between countries, with low-emission developed countries ranking higher because of their imports and high-emission developing countries ranking lower because of their exports. This could present a much fairer sharing of the responsibility for climate change and could also encourage production in countries with lower carbon emissions.

3.8 Summary of consumer behaviour: National scale consumption

This chapter identified that regardless of current consumption and reliance on the international market, a relatively simple shift in the manner in which electricity is generated could reduce New Zealand's emissions.

The electricity consumption and usage figures presented in section 3.1 show total usage per annum. By looking at total usage as opposed to per capita usage, the effects of population increases can be observed over time as the population has continued to increase. This made it possible to identify a shift in usage that suggests electricity consumption is decreasing per capita (figure 3.13).

Based on observed electricity generation and consumption data, there was a shift in consumption at the turn of the century. The embodied energy study of electricity generation (section 3.2) shows that since the turn of the century there has been an 8 per cent increase in electricity generated using renewable resources. Identified in section 3.2 (figures 3.4 and 3.5), since the year ending 1980, total electricity usage has increased just over a hundred per cent

(from 19,415 GWh to 39,201 GWh) with a population increase of approximately forty-five per cent over the same period. The changing trend line in electricity consumption observed over this period suggests a shift in behaviour (see figure 3.11) around the same time as policy surrounding electricity generation began to incorporate more renewable resources. Yet increasing CO₂ emissions in the energy sector do not reflect this change in behaviour, of lower usage and more renewable electricity. Is this solely due to an ever increasing population? As identified in section 3.6 (figure 3.18), annual household consumption patterns are following the same increasing trend depicted in the total electricity consumption of New Zealand. New Zealand's growing population may be to blame for the increase in emissions observed in section 3.5. This is substantiated by the total carbon footprint analysis, which shows that even though there has been an increase in (low carbon) renewable electricity sources used to generate New Zealand electricity, the increasing power demands of the rising population have meant the CO₂ equivalent emissions in the energy sector have increased.

While the annual electricity consumption over recent years is decreasing and future CO₂ emissions have the potential to be much lower by incorporating a solely renewable electricity mix, this investigation suggests that Jevons' observations are in effect. Though electricity generation technology has progressed to incorporate lower carbon means of energy generation, consumption continues to increase. Consumption per capita seems to be decreasing but the increasing population still means increased total consumption, regardless of how efficiently CO₂ emissions are reduced by using renewables. Being a hundred per cent renewable means emissions will still continue to rise over time, albeit much more slowly, because renewable energy generation technologies are not totally zero-carbon in construction.

Having explored a completely renewable electricity mix, and acknowledging rising population, this study identifies that New Zealand will not be able to meet the CO₂ reduction targets, identified at a conference of parties to the Copenhagen Accord in 2009 (NZ Parliament, 2011) or the new target emissions set in 2015, solely by moving to an all-renewable electricity mix. As a result the HEEP study is explored to understand behavioural and consumption patterns.

While electricity consumption (per capita) may be decreasing (although this may be due to a decline in manufacturing and other industries, rather than as a result of reduced household demand) as suggested by data from the Ministry of Business, Innovation and Employment (section 3.4, figure 3.13) the HEEP study shows that larger houses have a higher likelihood of

higher usage. The HEEP data identify appliance categories that comprise total household electricity usage (section 3.2.8, figure 3.26). However, this study does not show the number of appliances in the varying dwelling sizes, instead national averages are used. As identified in the HEEP study (refer to figure 3.23) household occupancy for many varying dwelling sizes remains the same, which suggests that house size is the significant factor to consider for increased consumption. While this makes sense for house heating and possibly water heating (refer to section 3.6, figure 3.26) the HEEP study does not show how this relates to increases in other appliance categories, such as entertainment, for high and low users.

As identified in section 3.7, the number of appliances could have a greater effect than is currently observed in the HEEP study. Perhaps even though dwelling electricity consumption per capita has decreased, appliances have increased in number. As a result, the embodied energy from this increase in appliance number could be responsible for greater emissions (an invisible carbon debt) even though electricity consumption is decreasing per household. The sheer volume of appliances even if not being used could well be responsible for a greater carbon footprint. This is an area that merits further research on appliance number per household.

This chapter identifies that a solely renewable electricity generation mix does provide a reduction in New Zealand's total (not only electricity) CO₂ equivalent emissions. This chapter also reveals that these reduced emissions still fall short of Kyoto Protocol targets set in 1992 (which changed again in 2009 and 2015) by New Zealand. While this investigation addresses the question first posed by Rule, Worth and Boyle (2009) of the likely merits of a solely renewable electricity mix, an investigation into population growth and increasing trends of consumption has identified that Jevons' observations are in effect. True to Jevons' observation, although technology has progressed to incorporate lower carbon footprint means of electricity generation, this has had little effect in stemming the rise of consumption. As a result, the next logical course of action to decrease emissions in spite of Jevons' paradox would be to adopt behavioural change that has the potential to affect all household energy consumption. Based on current increases in emissions, by sector, as identified by the Ministry of Business, Innovation and Employment, section 3.1 identifies that the best place to adopt behavioural changes is in the residential sector which is a consumer of forty per cent of all electricity generated in New Zealand. This is an area in which emission reductions may be possible, based on changes in individual decisions and personal behaviour in appliance ownership and usage.

A re-examination of the HEEP data has revealed that the top eleven per cent of electricity users in New Zealand are using twenty-three per cent of total residential energy. This is more than twice the amount of energy low users consume. This can be attributed to larger house sizes as identified by the HEEP study.

The question remains what aspect of these larger houses is it that governs the excess usage? Is this similar to usage patterns in houses of average size? A larger house will require more energy for space heating because the space is larger. But if the occupancy remains the same as in smaller houses, will water heating increase in the same way? Do the occupants of larger than average houses, who could be presumed to have larger than average incomes, tend to buy more appliances than the occupants of average size houses? The question of appliance number suggests the presence of possible *hidden emissions*. The number of appliances owned by a household could end up having a greater embodied energy than the operational energy of those same appliances. The relationship between these two factors will be strongly affected by the replacement rate of appliances and the way they are used. A possible answer to personal behaviour may well be as simple as owning fewer appliances and/or keeping the ones owned for longer before replacement. What is not yet known is the relative importance of the problem of *hidden emissions* and the likely effectiveness of these two possible behaviour changes in reducing it. In order to do a comparative study all embodied energy figures and operational energy figures would need to be calculated by dividing the total embodied energy by the assumed life to get an annual embodied energy figure to compare with the annual operating energy figure.

3.9 The next step: Chapter four

In order to further explore the significance of appliance number, Chapter four will identify the specific number of appliances in varying dwelling types to identify patterns of usage based on HEEP data not previously published. Chapter four will address the question of appliance number which suggests the presence of *hidden emissions*. The theory posited is:

The number of appliances is increasing the total CO₂ emissions due to the embodied energy of an appliance category (simply due to the fact that there is a greater number of the appliance in a dwelling), whilst the operational energy is not increasing as much for the appliance category in question.

To understand the relative importance of patterns of appliance usage and ownership, chapter four will establish the analytical framework and life cycle assessment (LCA) methodology. The LCA used to measure appliances is described, defining the methods employed to conduct this analysis on all appliances measured in each HEEP dwelling. These appliances will be specifically mapped for different types of dwellings as the current HEEP data identifies average New Zealand number of appliances based on an average of all the surveyed households. The HEEP data does not specifically look at the number of appliances in the different house sizes, household sizes or life stages. Chapter four will also identify the methodology of how the impact of behaviour is compared to house impact and provide a clear definition of an appliance for the purposes of this thesis.

Chapter Four

Research Methodology and Analytical Framework

While significant progress has been made in reducing Operational Energy; Embodied Energy has been largely ignored. However, these topics are strongly linked and should be considered as a “Balance Equation”, where all factors must be carefully measured in order to avoid the excesses of both.

- Waldron et al. (2013, p. 1264).

4.1 Methodology and analytical framework: Introduction

The sources identified in chapters one, two and three, frequently utilize the terms, embodied energy and operational energy, with no specific mention of how these are determined; i.e. what the measurement units are or what the measurement process entails. The methodology of this measurement process involves a rather complex analytical process. Establishing this methodology is the focus of this chapter. As identified in chapter one (section 1.10) system boundaries, such as the example by Ramesh et al. (2010), identify where the embodied energy and operational energy measures come from during the life of a product. These can be simplified down to the production phase or the embodied energy and the use phase, or operational energy. Based on these kinds of system boundaries many industry

statistics, like the ones mentioned in chapter one (Mohammad et al., 2013) and researchers (Shoubi et al., 2015) suggest that operational energy is the biggest impact variable and the embodied energy, in comparison, is insignificant. However, as discussed above, and earlier by Ramesh et al., even though there is a lot of emphasis on operation energy as the biggest impact variable, there are many researchers who have claimed that embodied energy may not be the biggest variable, however, this may still be significant. Professor Roger Fay's works (Fay et al., 2000) are examples of this and there are also other sources explored in other parts of this thesis that support this claim as well (J.B. Guinée, 2002; Wu et al., 2010). Here, the argument introduced at the beginning of this chapter by Waldron et al. (2013) presents an interesting theory of the *balance equation*.

Proponents of the *balance equation* suggest that any changes in the efficiency of a product will likely mean less operational energy and more embodied energy due to more sophisticated design processes or advancements in efficiency (Waldron et al., 2013, p. 1264). Hence, the need for a *balance equation*. Decreasing operational energy at a significant cost to the embodied energy could be considered an uneven balance. In order to establish such *balance equation* comparisons, an impact assessment of both the embodied energy and the operational energy must first be completed.

The conventional method for conducting an impact assessment of products that use energy and raw materials is based on the total energy expenditure and also the emissions associated with the production, use and end of life treatment, in many cases absorption back into the environment, either by recycling or storage in landfills. In order to determine the scale of impacts, a life-cycle assessment (LCA) is commonly used (Meijer, 2006, p. 82). There are many precedent examples of LCA methods and studies in contextual research in this area (Baird and Chan, 1983; Alcorn, 1996; Alcorn, 2003; and Mithraratne et al., 2007). Mithraratne et al. (2007, pp. 34-36) identify three analytical approaches to conducting an LCA, these are:

1. Input-output analysis (Baird and Chan, 1983);
2. Process analysis (Alcorn, 1996);
3. Hybrid analysis (Alcorn, 2003).

All three of these processes are described in detail by Mithraratne et al. (2007), establishing the fundamental strengths and weaknesses of each approach. Mithraratne et al. describe the Process analysis as follows:

This is regarded as the most accurate and most common method (Alcorn, 1996, p. 7) as it focuses on the energy requirements of a particular process. All processes outwith the defined system boundary are disregarded. Analysis begins with establishing the direct energy inputs to the production process under consideration and then traces back all the other contributory processes with their raw material requirements. Since all the direct energy requirements of all processes within the system are considered, this provides a reasonably accurate result. However, the effort required to account for all the tributary processes involved is not justifiable in most cases, while the method is also very time consuming owing to the complexity of an often increasing number of interconnected processes. The results are case specific and therefore are not representative of similar processes at other locations or times. Further, there may be processes for which data cannot be obtained owing to commercial sensitivity, lack of data collection or lack of data in an easily retrievable form. (Mithraratne et al., 2007, p. 36).

Based on the accuracy of this method, the specific analytical approach used in this thesis to measure impacts of behaviour in embodied energy and operational energy is an LCA that uses the Process analysis approach.

To this end, this chapter will first establish a definition of an LCA and identify what the process of an LCA involves, including the types of data required, as prescribed by existing standards and guidelines. Having established what is needed to conduct an LCA this chapter will then identify the key obstacles faced in the procurement of raw data and the actual process followed to meet the basic requirements of the governing standards. Finally, this chapter will outline the resulting analytical framework, will provide a clear definition of an appliance for the LCA and describe how CO₂ emissions will be calculated.

4.2 What is an LCA and what does the process of an LCA involve?

As defined by Ahmad et al. (2016, p. 188), an environmental impact is any change to the environment, whether adverse or beneficial, wholly or partially resulting from an

organisation's activities, products, or services. These impacts start as soon as raw materials are acquired and then incorporated during manufacturing to create a product.

Ahmad et al. (2016) argue that in the case of residential appliances, the biggest environmental impacts may occur when a product is being used in a residence. Specifically, energy and perhaps water are consumed when using the appliances, which may deplete water and fossil fuel sources and contribute to the carbon footprint of the user. The disposal of products at the end of their service life likewise contributes to environmental impacts through the use of energy to transport them from the location of use and relocate them, plus the impact of disposal in landfills, incineration, or other methods.

Because of recognised impacts over the full life of products and materials, there has been increasing interest in finding a reliable method for quantifying, comparing, and documenting the comprehensive environmental impacts related to specific products.
(Ahmad et al., 2016, p. 188).

The analysis of the environmental impacts at each stage of a product's life cycle is based on a standardised life-cycle assessment (LCA) process. The development of standardised LCA methodologies (discussed in the following sections) has led to the standardisation of how the results are reported. An Environmental Protection Agency (EPA) paper written by the Scientific Applications International Corporation (SAIC and Curran, 2006) identifies that these reports are quickly becoming the standard for identifying and communicating the total environmental impact of products, including appliances (SAIC and Curran, 2006, p. 45).

4.2.1 Life-cycle assessment overview

LCA is an analysis of all parts and phases of a product's life, from the extraction and implementation of raw materials to the end of its useful service life. The internationally recognised definition is the “*Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*” (The International Organization for Standardization, 1997, p. 2). The life cycle begins with the “cradle” of the product; the extraction of raw materials, processing of these and the shipping of the processed materials to the manufacturing site. This is followed by the manufacturing phase, in which labour, equipment, and energy are utilised to convert the processed materials into the building material or a product. When these materials are processed, they are considered

to be at the “factory gate” and ready for distribution. In conventional building, the finished building products then move into the construction phase at the construction site and are incorporated into the building.

The post construction (or post manufacturing) LCA phases, known as the use phase and end of life (grave) phase, are described in detail by Arsenault et al. (2014). Arsenault et al. identify how an LCA holistically analyses total impact.

After installation of the products, when the building is placed into service the products live out their use phase, using fossil fuels and water to perform their functions in the case of household appliances. Finally, at the end of the useful service life of either the building or the product, then the end-of-life (so-called “grave”) phase emerges where decisions about disposing, recycling, or re-using are made. Some LCAs are more focused and are developed with a specific goal and purpose. Some examples include a cradle-to-gate analysis, which is concerned about the things that a manufacturer has direct control over. Other examples include an economic input-output analysis, social LCAs, and comparative LCAs. Overall, the idea behind any LCA is to analyse the selected product holistically, as opposed to looking at only parts of the product and their environmental impacts. (Arsenault et al., 2014, pp. 164-165).

Arsenault et al. specifically identify that from this point onwards an appliance is in its usage phase which specifically means the use of fossil fuels (in the form of energy) and water to complete their function. As a result, while most LCAs of appliances may conventionally look at energy consumed, water usage has also been a similarly strong focus for appliances like dishwashers and clothes washers that need water to operate. LCA studies have found, for example, that many dishwashers have become so efficient in their use of water that it is now much more favourable to the environment to wash dishes using a dishwasher compared to hand washing.

By reducing the water consumption overall, water as a resource is depleted less and the environmental impact of processing and treating that water is less. (Arsenault et al., 2014, p. 167).

Previously, the evaluation of environmental impacts over the life of a product relied purely upon manufacturers' claims (Arsenault et al., 2014). However, there are now independently

conducted life-cycle assessments based on established standards that allow independent bodies to compare environmental attributes between similar products. This has come about through the development of several fundamental standards and guidelines.

4.2.2 Standards for “green” building design

The U.S. Green Building Council standards for good design have now started to distinguish environmental impacts of products and materials incorporated into and used in buildings (U.S. Green Building Council, 2016). However, as discussed by Arsenault et al. standards such as these do not do very much to consider the environmental impact of behavioural decisions such as appliance ownership and use during the life of the building (Arsenault et al., 2014). As defined in the previous section, an environmental impact is any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products, or services. These impacts start as soon as raw materials are acquired and then incorporated during manufacturing to create a product (U.S. Green Building Council, 2016). It is widely accepted that human activity has been largely responsible for climate change and therefore policies have been developed aiming to reduce the problem (Commissions, 2012; Abanda et al., 2012). Nevertheless, these policies again do very little to consider the behavioural choices that lead to unsustainable human activities.

Much like Shoubi et al. (see chapter one, section 1.10), Arsenault et al. (2014) identify that the biggest environmental impacts for household appliances may occur when an appliance is being used in a residence. Specifically, energy, and sometimes water, are consumed when using the appliances, which deplete water and fossil fuel sources and contribute to the carbon footprint of the user. At the end of their service life, the disposal of appliances also contributes to environmental impacts through the use of energy to transport them from the location of use and relocate them to landfills where more energy is used to dispose of them. Arsenault et al. identify how these recognised impacts have increased the interest in measuring and comparing these impacts.

Because of these recognised impacts over the full life of products and materials, there has been increasing interest in finding a reliable method for quantifying, comparing, and documenting the comprehensive environmental impacts related to specific building products. (Arsenault et al., 2014. p. 1).

While the LCA process provides a good indication of total impact of the building itself and products used in construction (sometimes considering things like fixtures, carpet, etc.), as discussed earlier in chapter one (section 1.10) a conventional LCA study of a building does not include a detailed analysis of the number of appliances occupants own and/or use when occupying a building. As a result, this methodology does not account for appliance number as discussed in chapter three. In order to account for this, international guidelines and standards must be selected and used to understand and ultimately establish a detailed method for conducting an LCA specifically for appliance impact.

4.2.3 International standards

With over 21,569 international standards published to date and members spanning across 162 countries, the International Organization for Standardisation (ISO) (2006a; 2006b) has become recognised around the world for establishing standards for a variety of different industries and methodologies, including the development of LCA standards and rules (ISO, 2017). The published standards in the ISO 14000 series address a broad range of environmental management. Specifically, the document ISO 14044 details the requirements and guidelines for conducting an LCA. Other related ISO standards and publications address LCA principles and framework (ISO 14040), data documentation format (ISO/TS 14048), and illustrative examples (ISO/TR 14047, 14049).

Certification to the ISO 14000 environmental management series of standards is being pursued most frequently by firms in Japan, the United Kingdom, Sweden, Spain, Australia, and the United States. Firms in the United Kingdom account for twenty per cent of the ISO 14000 certifications in Europe and ten per cent of the certifications throughout the world. (Yates and Castro-Lacouture, 2016, p. 77)

The British Standards Institute (BSI) developed its first environmental management standard in 1992, the British Standard Number 7750 (BS 7750). It was followed by the European Union (EU) Eco-Management and Audit Scheme (EMAS) in 1993. During this same period, individual countries developed their own standards, such as IS 310 in Ireland, X30-200 in France, UNE77-801 in Spain, SABS-0251 in South Africa, and CSA 7750 in Canada (Elefsiniotis and Wareham 2005, p. 208). The ISO developed and issued the ISO 14000 series of environmental standards in 1996. ISO 14000 is a series of standards:

aimed at providing organisations with a structured framework to manage their environmental impacts and responsibilities; however, the emphasis is on the management process, which aims to be consistent and which, in turn, should generate products of consistent quality. Some of the ISO 14000 series of standards (the Organization Evaluation group) concentrate on an organisation's management, environmental auditing, and environmental performance evaluation systems, whereas others (the Product Evaluation group) include things such as environmental labelling, LCA procedures, and product standards. In the latter case, there is an intuitive link to sustainable development because practices such as design for the environment can be included, which involve answering questions about the life cycle of the product and its production process. (Elefsiniotis and Wareham, 2005, p. 208).

To evaluate the impact of using product LCA, standardised techniques were developed to quantify the environmental effects during their use. ISO 14040 identifies how LCA methods can assist manufacturers and researchers in (International Organization for Standardization 14040, 2006, p. 1):

- *Identifying opportunities to improve the environmental performance of products at various points in their life cycle;*
- *Informing decision makers in industry, government, or nongovernmental organisations (e.g., for the purpose of strategic planning, priority setting, product or process design, or redesign);*
- *Marketing (e.g., implementing an ecolabeling scheme, making an environmental claim, or producing an environmental product declaration);*
- *The selection of relevant indicators of environmental performance, including measurement techniques.*

ISO 14040 (International Organization for Standardization 14040, 2006, p. 1) also states:

For practitioners of LCA ISO 14044 details the requirements for conducting an LCA. Life-cycle cost assessments address the environmental aspects and potential environmental impacts (e.g., use of resources and the environmental consequences of

releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave).

A standardised LCA study is described as being made up of four phases (International Organization for Standardization 14040, 2006a, p. 1):

- Goal and scope definition
- Impact assessment
- Inventory analysis
- Interpretation

As a result of all of the aforementioned ISO documents, there are detailed guidelines for conducting an objective LCA. Following the internationally adopted (as identified earlier in this section) ISO protocols, an ISO-compliant LCA can be conducted by an independent third party, ensuring that accepted methodologies are used to perform the LCA and that the results should be consistent with LCAs that follow the same methodologies. Therefore, this thesis is using the same methodology described in the ISO 14000 series for establishing the impact of appliances as an important factor for measuring behavioural impacts as outlined in chapter three. To that end, the LCA *goals and scope definition* are presented at the end of this chapter, followed by the *Impact assessment, inventory analysis* (including the quality assurance and sensitivity studies for these), and *interpretation* in the following three chapters.

4.3 What types of data are needed?

The proposed methodology for conducting the LCA process in this research, is based on the method of LCA as standardised by the ISO (International Organisation for Standardization, 2006a; 2006b). As prescribed by these standards and guidelines, the types of data needed to complete this LCA include a life cycle inventory (LCI); product specific rules (PSRs); and finally usage. These are shown in figure 4.1.

4.3.1 Life Cycle Inventories (LCI)

The lists of materials used to create appliances and their material quantities are known as the Life Cycle Inventories (LCI). A fundamental aspect of any LCA is the procurement of appropriate datasets of LCIs for each product so that the impact of products can be measured accurately. The most appropriate sources for establishing LCI datasets are the manufacturers' specifications of the products for which an LCA is to be done. LCI datasets of material quantities are specifically used in the calculation of the embodied energy of a product, these do not consider the operation of the product.

4.3.2 Usage and energy data

The usage and energy data specifically identify the key quantitative figures used in the LCA, these include:

- Numbers of appliances in each household (ownership);
- Usage breakdown – number of hours each appliance is used (operation);
- Representative appliance wattages.

4.3.3 Product Specific Rules (PSRs)

In order to conduct an LCA appropriately, product specific rules (PSRs) can be established based on the type of products for which an LCA study is conducted. These PSRs are conventionally developed by the one doing the LCA, which can be an organisation, an individual researcher or a manufacturer (Zbiciński et al., 2006, p. 193). Products can have very detailed PSRs that identify specific rules relating to the use of that particular product. A hypothetical example of this is a stapler. In order to identify the specific manufacture and use of a hand-operated stapler, a PSR would define the embodied energy of the stapler by using the embodied energy coefficients and weights of all of the raw materials used to create the stapler. However, this PSR would also identify that based on the manner in which a stapler is used, the "operational energy" of the stapler would be measured by the embodied energy of the staples used in the stapler. The staples in this instance can be considered the fuel expended in the operation of the stapler.

4.4 Procurement of raw data

The conventional sources for all of the aforementioned data requirements are shown in figure 4.2. While these are not set requirements for where data comes from, these are the obvious sources to use for the most accurate figures.

Figure 4.2: Conventional data sources: Where the most accurate figures can be sourced from.

As shown in figure 4.2, the most accurate figures for the various data required for an LCA comes from three sources. These are, the LCA conductor (i.e. the one conducting or carrying out the LCA), who develops the PSRs as discussed in the previous section; manufacturers, for materials quantities and wattages; and finally survey data, to establish appliance ownership figures and hours of operation. The latter involves the use of case study household to establish representative ownership and operation figures.

While the case study approach underpins many research projects (AVETRA, 2011, p. 1), the use of a life cycle assessment method for a large study pool involves some limitations. Various recent work has noted that one of the major limitations of a life cycle analysis is that it involves time-consuming manipulation of large quantities of data (Fernandez et al., 1997; PCA, 2016; and Hammond and Jones, 2016), but no solutions to this problem have been proffered beyond a number of life cycle analysis tools that have been developed for general building professionals. (PCA, 2016). In order to understand the effect of behaviour in New Zealand households, the relatively time-consuming task of conducting a life cycle analysis is increased by the requirement for a representative pool of case studies, for which energy and usage data would also need to be collected.

In response to these limitations, the case studies selected for this thesis are taken from the *Household Energy End-use Project (HEEP)*. The HEEP study is an unprecedented investigation that looked at energy use in nearly four hundred households around New Zealand. The study, that took approximately ten years, surveyed occupants and physically tested household equipment. Much of the data collected over this long term were never published or subsequently investigated in detail.

The value in using the HEEP case studies is the large dataset and the number of diverse case studies that were included in the investigation. The households surveyed in the HEEP study present the only real solution to the many variables that can be observed in behaviour when sampling a small number of case studies. Ragin (1987) claimed the solution to such a “many variables, small N” problem is “many variables, large N.”

As identified by Seawright and Gerring (2008) where causal variables are continuous (such as the large variation of human behaviour) and the outcome is dichotomous (either high or low impact), the researcher may employ discriminant analysis to identify diverse cases (Seawright

and Gerring, 2008, p. 301). Any study of behaviour or usage would by definition fit the description of “diverse” as discussed here by Seawright and Gerring, the outcome sought would be to understand usage and thus the results are attempting to ascertain what is and is not sustainable.

Diverse case selection for categorical variables is also easily accommodated in a *large-N* context by using some version of stratified random sampling. The HEEP case studies consist of diverse cases that were randomly selected, at the same time they include a number of non-random samples for regional coverage (BRANZ, 2003, p. 3).

These case studies provide the required data of appliance numbers and usage and at the same time they offer a diverse representative mix of New Zealand households and display a range of behavioural practices.

The HEEP case studies incorporate diverse family types and household occupancies which will allow this research to gain multiple perceptions of behavioural practice in New Zealand dwellings.

4.5 Key obstacles faced in the procurement of raw data

During the data collection phase of this research, one of the major setbacks experienced was a lack of data availability or an unwillingness to share data in industry. Many manufacturers choose to keep product details confidential, citing allowances outlined in ISO14044. Information withheld included lists of materials and materials quantities that make up their products (LCI).

This is predominantly due to the implications sharing such data may have on intellectual property and the potential unwanted exposure of their products. There are some published manufacturers' data sources used in the LCI data collated in chapter five, nevertheless, these only comprise one or two of the appliances examined in this study.

Hence, most of the LCI data established in this study came from a hands-on approach of physically dismantling appliances (*a tear down study*, defined in the following section) coupled with reported figures found in *open source repositories*.

Therefore, establishing the LCI data was a rigorous task for which many quality assurance checks were now required in the *model followed*, as discussed by Zbiciński et al. (2006, pp. 119 - 120), see figure 4.3. Zbiciński et al. identify the various requirements that are put on data quality for establishing appropriate LCI data sets.

Another challenge was some of the inconsistencies found in raw data collected during the ten-year HEEP study. In this raw data, there are some instances in which the reporting of hours of operation is inconsistent for some appliances. In these instances, the sensitivity study (see chapter six) identifies assumptions made for missing figures in the appliance operation study. See appendix A for the survey questions used in the collection of the raw data used in the LCA.

4.6 The actual process followed

This section of this chapter outlines the actual process followed in the LCA. Detailed descriptions of the process stages are described, detailing the specific methods for how reliable LCI data is procured and what the specific PSRs are.

Due to the obstacles faced in the procurement of the necessary data, an alternative method is developed to establish reliable data. Figure 4.4 identifies the alternative model used for the LCA. Alternative data collection methods are employed to establish LCI data sets, representative wattage figures for appliances and a sensitivity matrix for all appliances to approximate representative hours of use.

These methods include the use of 'open source repositories' and a 'tear down study' to quality assure the selection of open source repositories and also the use of 'aggregated data'. The definitions of these methods and the steps taken to quality assure them are discussed in the following sections.

Figure 4.4: LCA Model followed in response to data unavailability.

4.6.1 Tear down study

A tear down study is the hands on approach followed to determine the materials and material quantities used in the manufacture of the varying appliances examined in this study. In the absence of sound manufacturing data, appliances are physically dismantled to determine all the materials (and their quantities) used in the manufacture of appliances. One of the major limitations of this approach is the identification process of all of the materials found in appliances, while many materials are easy to recognise, there are some materials that cannot be accurately identified without significant chemical analysis of the unidentified material. In this case, many assumptions are made about what materials are. This is a high-risk approach as there can be a big difference in the embodied energy coefficients of materials that look the same, this is why the research also makes use of data LCI from open source repositories as defined below.

4.6.2 Open source repositories

For the purposes of this study the term open source repository is used for any LCI data source found in publicly available forums. These open source repositories consist of a combination of sources. While some are peer reviewed publications, there are many that are found in sources that could be considered non-scholarly impact analyses conducted by independent organisations and also standalone datasets that are not peer reviewed. The open source repositories used and their reliability are discussed in detail in chapter five. All final LCI datasets are based on these open source repositories after establishing their reliability by comparing their findings with figures found in the tear down studies. This is why a comparative analysis is conducted between LCI data procured during the tear down studies and the data found in open source repositories. This comparison is a quality assurance measure taken to more accurately establish LCI data from open source repositories.

4.6.3 Aggregated data – using across unit figures

When conducting an LCA on a house, very specific data about the house itself is used. However, when conducting an LCA for products like appliances, that occur in many households, it is important to establish LCI data that can incorporate a generic representation of an appliance. The difficulty of examining the impact of appliances is the various ways in which nearly every appliance is manufactured. For instance, the housing of a toaster can be

manufactured with plastics, stainless steel, copper or an innumerable number of materials. Each of these different types of toasters will also have varying amounts of materials for parts they all have in common. For this reason, many different toasters were examined.

When many different examples of an appliance are considered, varying material quantities are identified across many individual units of a particular appliance type, such as a toaster. Individual toasters of various sizes and forms (units) from many manufacturers will be examined. These data, called here *across unit figures*, can be considered to be a combination of data that best represents an appliance. This type of data validation is based on data that are aggregated, and for the purposes of this study data collected in this manner is dubbed *aggregated data*. *Across unit figures* are used for both the material quantities and the wattages. These figures are established in chapters five and six.

4.6.4 PSRs

As discussed by Zbiciński et al. (2006, p. 193), detailed PSRs are conventionally developed by life cycle assessors (or conductors) in order to appropriately represent specific product categories. In order to measure impact based on varying appliance operation, specific categories must be established to measure the varying patterns of use observed in how appliances operate. In order to do this PSRs are established. The PSRs developed for this study are created considering how appliances are used and the resulting effect multiple appliances will have on total operational and embodied energy. Dubbed the *effect on operation* categories/formulae, the PSRs developed specifically for measuring appliance impacts are discussed in the following section.

For the purposes of this study, in order to measure appliance use appropriately, PSRs are allocated to groups of appliances based on how these are used and the effect their usage has on operational energy. The PSRs established later in this chapter, are based on how different types of household appliances function. Dubbed here the "effect on operation" formulae, these PSRs also form the analytical framework used to measure the impact of household appliance use and behaviour. The analytical framework is identified in the following section.

4.7 Analytical Framework: "Effect on operation" formulae

Publications in both the construction industry and academia recognise that life cycle impacts or total impacts are conventionally determined by combining total embodied energy

and operational energy (Anderson et al., 2012, p. 7; Hakansson et al., 2013, p. 302). This may be represented by equation one.

$EE + OE = Total\ Impact$
- Equation 1

But what happens to this equation when appliance number increases? Having two of the same appliance would increase the embodied energy by two, however, this would not necessarily increase the operational energy in the same way, depending on how the appliances were used. This calls into question the effect appliance number (linked to purchasing behaviour) has on the operational energy.

In order to substantiate the theory of “Invisible Emissions”, this study looks at the number of appliances in each HEEP household. This provides an indication of how household decision making may impact usage. The aim is to understand the extent to which behaviour dictates appliance ownership, what effect this has on the operational energy for each appliance type and whether or not “Invisible Emissions” are present due to increased ownership (and increased EE as a result).

In order to consider this new variable, not considered in the conventional equation (Equation one above), this research proposes the “Effect on Operation” approach. The “Effect on Operation” approach will identify how behaviour affects operational energy for different categories of appliances and whether or not embodied energy (which is related to appliance number) is significant.

As identified in section 3.2.9, the theory of hidden emissions identifies the possibility of an increase in CO₂ emissions resulting from the number of appliances in a dwelling. The hair-dryer example used in section 3.2.9 suggests behaviour has a vital link to how an increased number of the same appliance can affect embodied energy without changing the operational energy.

However, in order to assess the effect of an increase in the number of appliances, all appliances need to be categorised based on the extent to which an increase in number will be likely to affect the total operational energy. Based on how each type of appliance may be used, each appliance will have a different effect on operational energy. The “Effect on Operation”

approach differentiates categories based on the change they are likely to cause in operational energy, resulting from an increase in appliance number. The three categories proposed for Effect on Operation are Proportional Change; Unchanged – concurrent use; Unknown Increase.

4.7.1 Proportional change

The “proportional change” category is used where appliance number has a direct correlation to operational energy, a correlative response resulting in a proportional change. This category may be represented by equation two:

$$EE + OE = Total Impact$$

$$\left(\sum_{i=1}^{n_{appliance}} EE_i \right) + \left(\sum_{i=1}^{n_{appliance}} OE_i \right) = Total Impact$$

Where:

$n_{appliance}$ = number of appliances

EE = embodied energy of each varying appliance

OE = operational energy of each varying appliance

i = index of summation

EE_i is an indexed embodied energy variable representing each successive term (appliance) in the series. The "i = 1" under the summation symbol means that the index i starts out at 1 for the first appliance. The index, i, is incremented by 1 for each successive term (appliance), stopping when i = n_{appliance}

- Equation 2

The proportional change category applies to appliances that proportionally increase operational energy simply by having more of these appliances. Refrigerators, for instance, would tend to have a proportional increase in operational energy depending on the number of refrigerators in a dwelling, but this would not necessarily be as simple as three refrigerators using three times the energy of one refrigerator because different refrigerators will have different consumption (equation two).

4.7.2 Unchanged

Represented by equation three, the “Unchanged” category is used where appliance number is independent of the operational energy, an independent response that means the operational energy remains unchanged regardless of the change in appliance number.

$$EE + OE_{original\ total} = Total\ Impact$$

$$\left(\sum_{i=1}^{n_{appliance}} EE_i \right) + OE_{original\ total} = Total\ Impact$$

- Equation 3

Equation three applies to two distinct “Unchanged” categories, concurrent and non-concurrent use of increased appliances. For instance, based on how it is used a hair dryer could be considered a “concurrent use” appliance. This is an appliance that, if several are owned, may be used by the same number of dwelling occupants at the same time, as discussed in section 3.2.9. On the other hand, a “non-concurrent use” appliance, would be an appliance that is an unused extra appliance. For example, a refrigerator in the garage that is stored in the case of a malfunctioning refrigerator, or an electric BBQ that is used if a portable gas fuelled BBQ runs out of gas. In both of these scenarios, the operational energy remains unchanged.

4.7.3 Unknown increase

The “Unknown increase” category applies to appliances for which appliance number causes an unknown, often variable, increase in original operational energy. This category may be represented by equation four.

$$EE + OE_{original\ total} = Total\ Impact$$

$$\left(\sum_{i=1}^{n_{appliance}} EE_i \right) + x(OE_{original\ total}) = Total\ Impact$$

- Equation 4

The “Unknown increase” category implies causation. In these instances, there may be appliances that have a causal relationship with operational energy. For this appliance category, an increase in appliance number is considered to have a cause-and-effect relationship, whereby simply having more may increase operational energy, though this may not necessarily be a proportional increase.

It is important to remember that an LCA is a complex modelling tool that has to rely on the best possible materials data available to provide an accurate estimate of impacts. Attempting to source this data has, for the duration of this research, proved to be a very difficult task. Nonetheless, becoming aware of where the biggest environmental impacts in a product's life cycle exist may help to identify clear directions for making important changes to reduce those impacts. In order to accurately conduct an LCA a clear definition of an appliance is proffered in the following section.

4.8 The definition of an appliance

In order to identify the methods to be used for an LCA study of appliances, a clear definition of an appliance is needed. The Merriam-Webster dictionary defines an appliance as: *“...an instrument or device designed for a particular use or function <an orthodontic appliance>; specifically: a household or office device (such as a stove, fan, or refrigerator) operated by gas or electric current”* (Merriam Webster Dictionary, 2017). An appliance described by this definition of a device operated by gas or electricity covers a broad range of household products that may lie outside the scope of this research that is looking at the impact of behaviour in the act of dwelling. For this, the conventional definition needs to be refined.

In order to measure appropriately behaviour in the act of dwelling, the definition of an appliance needs to consider a distinction between fixed appliances, which could be considered parts of the house construction, such as heat pumps, lighting and central heating systems, in comparison to more portable appliances that are not fixed.

This is best observed by considering all of the appliance ownership choices and day to day operation that will likely affect the total impact of a household. For this reason, an appliance is defined here, in its most basic form as:

a household energy-using product that is/can commonly be, replaced (or made redundant) by household occupants. This includes all light bulbs, cooking appliances and portable heating appliances.

Therefore, this definition of appliances does not extend to all fixed 'appliances' such as hot water heating systems, central heating or underfloor heating systems etc. Appliances like these are measured as part of the impact of the house construction as opposed to the impact of behaviour in the act of dwelling. Excluding fixed appliances such as central heating systems and hot water heating appliances, has the potential to create a data void in this area of research. However, one of the main focal points of BRANZ research, including HEEP, and many other studies- ongoing and already published, focus on this area, looking specifically at central heating systems like heat pumps and also water heating fixed appliances that are considered part of the house construction. (BRANZ & Howell, 2010; BRANZ & Isaacs et al., 2010; BRANZ & Burrough 2011; BRANZ & Page 2009; BRANZ & Pollard, 2010).

Also, other methods of LCA (namely the input output method, identified earlier in this chapter, discussed in detail by Mithraratne et al., 2007, and Alcorn, 2003) conduct LCA based on construction cost which include central heating systems and water heating systems. However, these do not include all fixed appliances that household members introduce into the house in the act of dwelling. Fixed appliances like stoves and hobs are more commonly not considered part of house construction with the rise of kit-set housing and developer catalogues. (Lockwood 2017; Builtsmart 2017; Trenzhomes 2017)

This is also the practice of Housing New Zealand, where “appliances” such as hot water heating and central heating systems are covered as part of the construction cost/impact. However these fixed appliances do not include all fixed appliances like stoves (even fixed stove tops) as these are replaced more often by household members. (Housing NZ Design Guidelines, 2015). Hence, house construction LCA covers the appliances this study deliberately does not cover. An embodied energy study conducted in 2014 (Bakshi et al.), looked at embodied energy and new technologies. This paper looked at the embodied energy of newer appliances and found

that newer technology has much bigger embodied energy resulting from an effort to reduce operating energy. This raises concerns that are analogous with concerns raised by Waldron et al. and the need for the balance equation, discussed earlier in this chapter. Based on this definition of appliances, presented in this section, more detailed appliance categories are established in chapter five.

4.9 Material coefficients

In addition to the ISO guidelines, guidelines presented in Frischknecht et al. (2004) and the Inventory of Carbon and Energy database (see below) are used to assign embodied energy coefficients (and CO₂ coefficients, discussed in the following section) to the LCIs of each appliance.

Rather than accumulating multiple literature sources, all material coefficients are established using the Inventory of Carbon and Energy (ICE) version two database. (Hammond and Jones, 2016). Created from a large international review of the literature, the ICE database provides representative embodied energy and CO₂ coefficient data that is used around the world to measure impact (Hammond and Jones, 2016). As discussed by Hammond and Jones, this database has undergone a rigorous evaluation process in order to identify substantiated international embodied energy coefficient figures.

The University of Bath's inventory of carbon and energy database lists almost 200 different materials. The data were extracted from peer-reviewed literature on the basis of a defined methodology and a set of five criteria. The database was made publicly available via an online website and has attracted significant interest from industry, academia, government departments and agencies, among others. Feedback from such professional users has played an important part in the choice of 'best values' for 'cradle to-site' embodied energy and carbon from the range found in the literature. The variation in published data stems from differences in boundary definitions (including geographic origin), age of the data sources and rigor of the original life-cycle assessments. (Hammond and Jones, 2008, p. 87).

As this database incorporates different examples of coefficients, the choice of a particular coefficient value is based on the average figure provided in the ICE database, unless otherwise

stipulated in the working documentation found in the supplementary information provided with this thesis.

4.10 CO₂ accounting methodology

CO₂ equivalent emissions for appliance manufacture and operation are calculated separately in order to account for place of operation, as well as the location of manufacture. As identified above, in order to account for CO₂ intensive countries in which appliances are manufactured, all embodied energy calculations are based on embodied energy CO₂ coefficients established in the ICE database version two. However, all operational energy is calculated using the CO₂ coefficients recorded for energy sources in New Zealand (New Zealand gas, coal and the New Zealand electricity mix). Hence, CO₂ emissions for the operation of all electrically powered appliances are calculated using the CO₂ intensity figure of 120 grams of CO₂ per kWh calculated in chapter three (see figure 3.16). This figure was later substantiated when the CO₂ intensity figure for the 2014 electricity mix was released by MBIE (Ministry of Business, Innovation and Employment, 2016). The emissions accounting figures for New Zealand gas and coal follow the same figures that are presented in chapter three and tabulated in the supplementary information provided in appendix D.

National estimates of total CO₂ emissions associated with household appliances are calculated based on a calculated average household CO₂ emission figure. Based on the average of CO₂ emissions of all case study households, this figure is the figure applied to the total number of households in the New Zealand building stock to give a national estimate of CO₂ equivalent emissions. Any and all reductions explored in this thesis subtract from total estimates of CO₂ equivalent emissions reported by the Ministry of Business Innovation and Employment (MBIE).

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Chapter Five

Life Cycle Inventories

LCA is receiving more and more attention in industry and authorities as one important tool for e.g., Integrated Product Policy (IPP), Technology Assessment or Design for Environment (DfE). In parallel with this increasing trend for LCA applications the demand for high quality, reliable, transparent and consistent LCA data increases as well. Only a few publicly available LCI databases fulfil these criteria, most of them from the 1990s and thus not up-to-date.

- Frischknecht and Rebitzer (2005).

5.1 Compiling life cycle inventories

To measure household appliance impact and to ascertain how behavioural choices of appliance use and ownership compare to the impact of a house, an LCA is conducted, as discussed in chapter four. In order to carry out this life cycle assessment, accurate LCI data must be established, a task made considerably more difficult due to a scarcity of data availability, as identified by Frischknecht and Rebitzer (2005).

As identified in chapter four, the life cycle assessment will be conducted based on the standards set in the ISO. Following the process and guidelines for conducting an LCA, all data collected and measured here will be publicly disclosed in this chapter. However, in accordance with ISO

14040 (International Organization for Standardization, 2006a) and ISO 14044 (International Organization for Standardization, 2006b) no details of manufacturing information or specific appliance models will be disclosed. Following the specification of the aforementioned standards, each appliance will be allocated material quantities as an example of the kinds of appliances found, i.e. quantities for “an average toaster”. In order to select the appropriate LCI figures, material quantity figures established in a tear down study are compared to data found in various open source repositories. The LCI data sets identified in this chapter are the outcome of these comparisons. The open source repositories referenced in this chapter are considered the most reliable and representative LCI figures available at the time of this thesis’ completion. As identified in the preceding chapter, due to the scarcity of publicly available appliance specifications from manufacturers, this approach is applied to most of the data collected in this thesis.

5.2 Appliance life spans and nominal weights

In order to establish appliance replacement cycles and impacts per annum, the life spans of appliances and their weights are identified here for all of the appliances recorded in each household in the HEEP survey. The sources used to identify appliance life spans and weights are identified in the table below followed by the LCI data sets for each.

These appliance life spans and weights are identified in table 5.0. Total weights are gathered to improve any material quantity assumptions made, where accurate figures are unknown or not disclosed by manufacturers for the protection of intellectual property.

Appliance	Life span (yrs.)	Weight (kg)	Reference
<i>General/Small Portable Appliances</i>			
Vacuum Cleaner Life span	3		(Douglass et al., 2007)
Vacuum Cleaner Weight		1.9	(Douglass et al., 2007)
Sewing Machine Life span	10		(North-Western, 2017)
Sewing Machine Weight		6	(Okocha, 2017)
Cupboard Heater Life span	4		(Cupboard Heaters U.K., 2016)
Cupboard Heater Weight		1.5	(Cupboard Heaters U.K., 2016)
Heated Towel Rail Life span	2		(Huile Industries Limited, 2016)
Heated Towel Rail Weight		3.7	(Huile Industries Limited, 2016)
Extractor Fan Life span	10		(ATD, 2016a)
Extractor Fan Weight		1.1	(Airflow, 2016)
Heated Fish Tank Life span	20		(Living Reefs, 2017; PetPlace. 2017; Michigan Reefers, 2017)
Heated Fish Tank Weight		5.38	(Sharpe, 2016; Hidom, 2016; Aquazonic, 2016)
<i>Entertainment Appliances</i>			

Television Life span	10		(Wenzel et al., 2001)
Television Weight		42.7	(Wenzel et al., 2001)
Computer/Games Life span	2		(Truttmann and Rechberger, 2006)
Computer/Games Weight		31.7	(Truttmann and Rechberger, 2006)
Video Player Life span	8		(Truttmann and Rechberger, 2006)
Video Player Weight		5	(Truttmann and Rechberger, 2006)
Separate Radio Cassette Life span	3		(Truttmann and Rechberger, 2006)
Separate Radio Cassette Weight		2.3	(Sony, 2017a)
Stereo Life span	3		(Truttmann and Rechberger, 2006)
Stereo Weight		9	(Logitech, 2016)
Television Decoder Life span	5		(Truttmann and Rechberger, 2006)
Television Decoder Weight		5	Assume the same as a video player
<i>Washing/Drying Appliances</i>			
Iron Life span	4		(Mezek et al., 2005, p. 8)
Iron Weight		1	(Mezek et al., 2005, p. 8)
Dishwasher Life span	10		(Gaudio et al, 2009)
Dishwasher Weight		20.2	(Gaudio et al, 2009)
Washing Machine Life span	15		(Bourrier, et al., 2011)
Washing Machine Weight		68.1	(Bourrier, et al., 2011)
Tumble Dryer Life span	13		(ATD, 2016a)
Tumble Dryer Weight		49	(Bossert and Waber, 2001)
Cabinet Dryer Life span	13		Assumed to be the same as tumble dryer
Cabinet Dryer Weight		3.7	(Trifate Appliances, 2016)
<i>Kitchen/Cooking Appliances</i>			
Refrigerator Life span	10		(Truttmann and Rechberger, 2006)
Refrigerator Weight		50	(Truttmann and Rechberger, 2006)
Combination Fridge-Freezer Life span	14		(Horie, 2004)
Combination Fridge-Freezer Weight		84	(Horie, 2004)
Deep Freeze Life span	14		(Horie, 2004)
Deep Freeze Weight		134	(Horie, 2004)
Toaster Life span	6		(Krause and Seliger, 1997)
Toaster Weight		1.1	(Krause and Seliger, 1997)
Electric Jug (Kettle) Life span	3		(Husiman, et al., 2007, p. 62)
Electric Jug (Kettle) Weight		1	(Husiman, et al., 2007, p. 62)
Coffee Maker Life span	6		(Neffa et al., 2014)
Coffee Maker Weight		1.6	(Neffa et al., 2014)
Food Processor Life span	4		(Cone et al., 2007)
Food Processor Weight		1.6	(Cone et al., 2007)
Mixer Life span	5		(Husiman, et al., 2007, p. 62)
Mixer Weight		2.4	(Husiman, et al., 2007, p. 62)
Bread Maker Life span	2		(Bread Machine Pros, 2016)
Bread Maker Weight		8.5	(Bread Machine Pros, 2016)
Rice Cooker Life span	4		(Cuckoo, 2016)
Rice Cooker Weight		1.4	(Panasonic, 2016)
Crockpot Life span	4		Assumed to be the same as a rice cooker
Crockpot Weight		1.4	Assumed to be the same as a rice cooker
Microwave Life span	10		(Truttmann and Rechberger, 2006)
Microwave Weight		23	(Truttmann and Rechberger, 2006)
Waste Master Life span	12		(ATD, 2016a)
Waste Master Weight		6.16	(InSinkErator, 2016)
Range Hood Life span	14		(ATD, 2016a)
Range Hood Weight		8.2	(Fisher and Paykel, 2013)
Electric Range (hob+stove) Life span	15		(Jungbluth, 1997)

Electric Range (hob+stove) Weight		64.1	(Jungbluth, 1997)
Gas Range (either gas or LPG) Life span	15		(Jungbluth, 1997)
Gas Range (either gas or LPG) Weight		69.5	(Jungbluth, 1997)
Electric Oven Life span	15		(Jungbluth, 1997)
Electric Oven Weight		57.9	(Jungbluth, 1997)
Gas Oven (either gas or LPG) Life span	15		(Jungbluth, 1997)
Gas Oven (either gas or LPG) Weight		57.9	(Jungbluth, 1997)
Wood/Coal Range Life span	15		(Jungbluth, 1997)
Wood/Coal Range Weight		161.9	(Jungbluth, 1997)
Separate Electric Grill Life span	15		Assumed to be the same as the electric oven
Separate Electric Grill Weight		13.2	Assume to be 25 per cent of the weight of an electric oven
Separate Gas Grill Life span	15		Assumed to be the same as the gas oven
Separate Gas Grill Weight		13.2	Assumed to be 25 per cent of the weight of a gas oven
Electric Hobs Life span	10		(Samsung, 2016)
Electric Hobs Weight		6.2	(Samsung, 2016)
Gas Hobs (either gas or LPG) Life span	10		(Samsung, 2016)
Gas Hobs (either gas or LPG) Weight		11.6	(Samsung, 2016)
Induction Cooking Life span	15		(Elduque et al., 2014)
Induction Cooking Weight		0.65	(Elduque et al., 2014)
Bench Top Mini Oven Life span	15		Assumed to be the same as the electric oven
Bench Top Mini Oven Weight		10	(Breville, undated)
BBQ LPG Life span	4		(Consumer NZ, undated)
BBQ LPG Weight		64	(BBQs Direct, 2016)
BBQ Charcoal Life span	7		(Weber, 2016)
BBQ Charcoal Weight		14.4	(Weber, 2016)
BBQ Electric Life span	4		(Weber, 2017)
BBQ Electric Weight		18.1	(Davis, 2012)
Electric Fry Pan Life span	4		Assumed to be the same as electric barbeque
Electric Fry Pan Weight		5.1	(Sunbeam, 2017)
<i>Space Heating Appliances</i>			
Single Electric Blanket Life span	5		(Chen et al., 2013, p. 10)
Single Electric Blanket Weight		2	(Biddeford, 2016)
Double Electric Blanket Life span	5		Assume to be the same as the single electric blanket
Double Electric Blanket Weight		4	Assume to be twice the weight of a single electric blanket
Portable Fan Heater Life span	10		(ASHRAE, 2013)
Portable Fan Heater Weight		1.3	(Impress, 2016)
Wall Fan Heater (bathroom) Life span	10		Assumed to be the same as the portable fan heater
Wall Fan Heater (bathroom) Weight		1.3	Assumed to be the same as the portable fan heater
Electric Radiator Life span	10		(ATD, 2016a)
Electric Radiator Weight		3.2	(Goldair, 2017a)
Portable Electric Radiator Life span	10		Assumed to be the same as the electric radiator heater

Portable Electric Radiator Weight		3.2	Assumed to be the same as the electric radiator heater
Portable Convection Heater Life span	10		Assumed to be the same as the electric radiator heater
Portable Convection Heater Weight		2.7	(DeLonghi, 2016)
Obsolete Electric Fan/Bar Radiator Life span	10		Assumed to be the same as the electric radiator heater
Obsolete Electric Fan/Bar Radiator Weight		10	(Lifesmart, 2016)
Electric Panel Heater Life span	10		Assumed to be the same as the electric radiator heater
Electric Panel Heater Weight		7	(Dimplex, 2009)
Portable Kerosene Heater Life span	6		(Dimplex, 2009)
Portable Kerosene Heater Weight		12.8	(Dura Heat, 2016)
LPG Heater Life span	4		(Clough, 2010, p. 25)
LPG Heater Weight		9	(World Marketing, 2016)
Dehumidifier (with heater) Life span	8		(ATD, 2016a)
Dehumidifier (with heater) Weight		20	(The Home Depot, 2016)
<i>Lighting</i>			
Incandescent Lamps-fixed/portable Life span	0.3		(U.S Department of Energy, 2017)
Incandescent Lamps-fixed/portable Weight		0.02	(Goodyer, 2012)
Halogen Lamps fixed/portable Life span	0.6		(Lightbulb Man, undated)
Halogen Lamps fixed/portable Weight		0.02	(Goodyer, 2012)
Compact Fluorescent fixed/portable Life span	4		(U.S Department of Energy, 2017)
Compact Fluorescent fixed/portable Weight		0.04	(Goodyer, 2012)
Heat Lamp Life span	0.3		Assumed to be the same as the incandescent lamp
Heat Lamp Weight		0.02	Assumed to be similar to the incandescent lamp
<i>Garage/Garden Appliances</i>			
Gas Lawnmower Life span	2	39.2	(Lan and Liu, 2010)
Electric Lawnmower Weight	2	12.3	(Lan and Liu, 2010)
Gas Weed Eater Life span	2	5.6	(Lezotte, 2013)
Electric Weed Eater Weight	2	5.34	Assumed to be similar to gas weed eater
Electric Power Tools Life span	1		(Bunnings Warehouse, undated.a)
Electric Power Tools Weight		2.26	(Berendsohn, 2015)
<i>Table 5.0: Appliance life spans and weights. All units are in years or kilograms. They are separated because the figures are often from different sources.</i>			

All appliance LCIs and their embodied energy impact calculations are appended at the end of this thesis (appendix C). The sources that are used to form table 5.0 are discussed in detail below.

A report published by the United Nations University (UNU) titled “*Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE)*” (Huisman, et al., 2007) is the

largest open source repository available. This report summarises the results of studies into the materials that constitute many electronic appliances and the waste produced by these appliances. Although this report identifies the contribution many electronic appliances make to total environmental impacts, this resource is used here to establish the life span and material quantities of the appliances in this thesis. The extensive data collected in this resource is reliable because one hundred and eighty-three different contacts were approached for interviews, questionnaires and specific data to gather a very complete data overview. (Huisman, et al., 2007, p. 4). This included determining:

1. Quantities of WEEE put on the EU market, the amount of WEEE arising as waste and the amounts collected and treated (which are three different levels),
2. The technologies used with specific focus on plastics recycling,
3. The environmental parameters over the total recycling chain,
4. The costs of collection, transport, treatment and recycling as well as overhead and administrative burden of the Directive. This includes also an overview of the implementation status in the EU27.

Thus, a large database with over three hundred and fifty literature sources is derived, as well as a fully updated environmental and economic assessment model that describes the sixty-four most relevant materials that constitute electronic appliances. (Huisman, et al., 2007, p. 4). Truttmann and Rechberger (2006) is another source used to identify the life cycle inventories for several household appliances. The study compares two standpoints; the first, the reuse of old appliances, which can potentially reduce production energy, and the second; new appliances can be more efficient and therefore have a smaller operational energy. Truttmann and Rechberger conclude that there is a trade-off between resource conservation during production and energy consumption. The paper investigated the material and energy balances of eight electronic appliances, of which six are identified in the HEEP study appliance list used in this thesis. These are:

- Computer (life span of two years)
- Video player (life span of eight years)
- Separate radio cassette (life span of three years)
- Refrigerator (life span of ten years)
- Microwave (life span of ten years)

Truttmann's and Rechberger's LCI figures are used for these appliances in the LCA conducted here. Much like the study by Truttmann and Rechberger, another study by Jungbluth (1997), titled "*Life-Cycle Assessments for Stoves and Ovens*", detailed various ovens and stoves using an LCA. Jungbluth specifically looked at stoves that used:

- Electricity
- Wood
- Liquefied gas
- Natural Gas
- Kerosene
- Open wood fire

The LCA was established using the method of Eco-indicator 95⁷, which was supplemented by an additional investigation of some environmental impact categories, such as space use and waste heat (Jungbluth 1997).

The study investigated how environmental impacts link with household consumption patterns using a survey. This found that there is a small environmental advantage when cooking with gas instead of electricity, based on the Swiss electricity mix. The material quantities and life spans identified by Jungbluth (1997) for five cooking appliances are used for this study.

This twenty-year-old reference is still an appropriate source as newer stove technologies seem to have the same materials quantities, as identified by the tear down study of two stoves. The tear down study dismantled a gas-powered stove and an electric stove top for the comparison of Jungbluth's LCI data set. The basic composition of materials and their quantities had almost no difference except for the loose insulation type found in the electric oven in the tear down study (see figure 5.1).

⁷ "The Eco-indicator method is a multi-step process. It starts with the calculation of the environmental loads from the product life cycle. In the following two steps the exposure and effect of the exposure, using average European data, are calculated. Then follows the critical issue: what should be considered an environmental problem. In the Eco-indicator approach three damage categories, so-called endpoints, are distinguished: Human Health, Ecosystem Quality and Resources" (Zbiciński et al., 2006, p.108).

Figure 5.1: Electric stove tear down study. Loose insulation found instead of rigid insulation filler.

The tear down study was conducted on old appliances, hence the similarities between Jungbluth's LCI data set and the tear down study findings are to be expected. Any future research would need to take this into consideration and possibly look at newer appliances to establish an LCI data set based on more current manufacturing practices.

Manufacturers such as Fisher and Paykel (kitchen appliances) and Stihl (garden appliances) publish some LCI data on their websites. These are the only manufacturers' specifications used in this study. For the all other appliances that had no data available, the Attention to Detail (ATD) home inspection database is utilised. ATD identifies life spans of common house materials, appliances, and mechanical plant (ATD, 2016a). Data published in this open source repository is based on investigations that review the condition of houses. This includes everything from the exterior cladding to the fixtures and fittings inside (ATD, 2016b).

5.3 Appliance categories

The next section presents the LCI data collected for all the appliances identified in the HEEP study. The HEEP study identified a large list of household appliances, these have been grouped into specific categories to present household appliances based on their use. The table below identifies the appliance categories established for the LCA process followed in this thesis.

As identified in chapter three, section 3.7, household usage of appliances in these categories has the potential to be either spatially related, where the size and/or number of spaces may affect usage, or personally related. The table below identifies the potential each category has for being either spatially or personally related. This table is based on the definition of appliance, that was established in chapter four.

Appliance category	Personally related	Spatially related
General, small portable appliances	✓	
Entertainment appliances	✓	
Washing and drying appliances	✓	✓
Kitchen and cooking appliances	✓	✓
Space heating appliances		✓
Lighting	✓	✓
Garage and garden	✓	✓
<i>Table 5.1: Appliance categories</i>		

For the purposes of this study, it is assumed that household appliance use of all appliances in the *general, small portable appliances* category are *personally related* as the ownership and operation of such appliances is based on the household occupants, i.e. not everyone will choose to have an individual microwave or electronic coffee grinder. Establishing all appliances in the *entertainment* category as *personally related* seems to be a logical assumption, however, the same cannot be claimed for appliances in the *washing and drying*, *kitchen and cooking* and the *lighting* categories.

Appliances in the *washing and drying* category are personally related as many household occupants can choose to not have a tumble dryer or any clothes dryers. However, the appliances

in this category are also spatially related as the size of a household and house may affect the number of washing cycles, and number of irons found in a house. Some *kitchen and cooking* appliances are also *personally* and *spatially related* as many people choose the fuel type to use for large cooking appliances such as stove tops and ovens. These also have the potential to be *spatially related* as they can be limited by the house size or location.

Household *space heating* appliances are difficult to define as there are many kinds of appliances that can be used to heat a household. It is for this reason that the definition of appliance in this thesis has strictly limited appliances to appliances that are not built into the house itself. However, there are some exceptions to this steadfast rule. Appliances such as electric towel rails, extractor fans, wall mounted heaters and waste disposal units (waste master) are appliances that can be fitted post construction and removed based on occupant's choice. This is considered a behavioural factor that cannot be ignored in the exploration of the impact of behaviour in the act of dwelling.

5.4 Quality assurance tear down analysis with open source repositories

As identified earlier, of the various appliances for which material quantities could not be established using manufacturer's specifications, a tear down study was carried out to establish the accuracy of the LCI figures. Quality assurance of this procedure involved an in-depth comparative study of the materials figures ascertained during the teardown analysis (some of which have various assumptions), which are then compared to data sourced from open source repositories. In order to quality assure all appliance LCI data sets, this comparative study procedure is followed. The tear down study figures are compared with data from open source repositories that are strategically selected based on the findings of these tear down analyses. Images of all torn down appliances are appended at the end of this thesis (see appendix C).

5.5 General, small portable appliances

5.5.1 Vacuum cleaner

A study, conducted at Carnegie Mellon University, disassembled nine to thirteen appliances twice a year, between the years 2007 and 2014. (Carnegie Mellon University, 2014. This study also identifies the life span and material quantities for five of the household appliances as identified in the HEEP study, these are:

- A coffee maker (six-year life span)
- Food processor (four-year life span)
- Dishwasher (ten-year life span)
- Vacuum cleaner (three-year life span)
- Mixer (five-year life span)

The vacuum cleaner LCI is presented here in the *general, small portable appliances* category. The other four appliances are presented later in the appropriate appliance categories as identified above in section 5.3.

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium, virgin	0.459
copper virgin	0.262
plastic - general	1.075
Rubber	0.002
Steel Virgin	0.109

Table 5.2: Vacuum cleaner LCI (Okocha, 2017).

5.5.2 Sewing machine

The North-Western University (in Evanston, Illinois) identified the useful life span of a sewing machine at ten years. Specific mechanical parts need to be replaced over the life span of a sewing machine. The useful life span depicts a period where the appliance is used before any repairs or replacements are undertaken (North-Western, 2017). Okocha (2017) undertook a comparative study to provide top choices for consumers. A survey was carried out by a fashion designer with over twenty years of experience to identify the seven *best* sewing machines. The following models were identified and compared in detail (Okocha, 2017). In accordance with ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b) no details of manufacturing information or specific appliance models are disclosed. This study only refers to the models compared in the Okocha (2017) study.

<i>Brand</i>	<i>Weight (pounds) - (kg)</i>
Brother	13.2 (6.00kg)
Brother	13.0 (5.90kg)
Brother	9.92 (4.50kg)
Brother	17.0 (7.71kg)
Singer	17.8 (8.07kg)
Singer	14.6 (6.62kg)
Janome	15.6 (7.07kg)

Table 5.3: Review of seven sewing machines (Okocha, 2017). The original study presented figures in pounds, which are converted here to kilograms.

The median weight of a sewing machine was identified as 14.6 pounds, which is approximately six kilograms (Okocha, 2017). As no LCI information is available for a sewing machine, the material quantities are based on the tear down study and assumed from figure 5.2 and based on the median weight identified above.

Figure 5.2: Isometric view of the components in a sewing machine (Made How, 2016a).

The online repository, Made How, identified the following raw materials that form the sewing machine (Made How, 2016a):

- Plastic/polymer casing
- Aluminium
- Copper
- Chrome
- Nickel
- Motor
- Steel

The final material quantities are identified in table 5.4.

Material	Weights (kg)
PVC Injection Moulding	2.9
Copper (Wiring)	0.082
plastic - general	0.87
PVC - general	0.006
Aluminium, virgin	0.8
Steel Virgin	1.16
copper virgin	0.0464
Chromium	0.0232
Nickel 8	0.0116

Table 5.4: Sewing machine material quantities.

5.5.3 Cupboard heater

The LCI data for the cupboard heater are assumed based on the heated towel rail material quantities, and the specifications identified by a manufacturer (Cupboard Heaters U.K., 2016). Cupboard Heaters U.K. identified the following raw materials:

- Aluminium tube alloyed with silicon, magnesium and iron
- Stainless steel rod
- Glass tube
- Plastic caps
- Coating of paint

Another manufacturer of cupboard heaters identified the weight of the appliance as 1.5 kilograms (Brett Productions, undated). An assumption is made that the coating of paint, silicon, iron and manganese around the heating tubes weighs two grams each. The plastic material is assumed to be the same as the heated towel rail because the plastic ends on the cupboard heater broken down in the tear down study are similar. The heating tube is constructed from aluminium and based on the dimensions (four hundred and fifty millimetres long by twenty-two millimetres diameter by 0.635 millimetres thick) it is assumed that the material quantity is 0.6 kilograms. The heating element is constructed from a stainless-steel rod enclosed in a glass tube, the material quantities are assumed to be 0.5 kilograms and 0.3 kilograms respectively. The final material quantities are detailed in table 5.5.

<i>Materials</i>	<i>Weights (kg)</i>
Paint - General	0.002
PVC - general	0.006
Aluminium, virgin	0.6
plastic - general	0.025
Copper (Wiring)	0.082
Silicon	0.002
Iron	0.002
Manganese	0.002
Stainless steel	0.5
Glass, float	0.3

Table 5.5: Cupboard heater material quantities.

5.5.4 Heated towel rail

The LCI of an electric towel rail is sourced from manufacturer's specification published by Huile Industries in China (Huile Industries Limited, 2017). With nearly two decades of

experience in the manufacture of electric towel rails, Huile Industries identifies the typical life span of a heated towel rail is two years. The LCI of a heated towel rail is presented here in table 5.6 (Huile Industries Limited, 2016).

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	3.51
copper virgin	0.13
plastic - general	0.025
Rubber	0.054
<i>Table 5.6: Heated towel rail material quantities (Huile Industries Limited, 2016).</i>	

5.5.5 Extractor fan

The ATD Home Inspection life span database identified the life span of an extractor fan as ten years (ATD, 2016a). “Airflow”, is a UK based manufacturer that identifies an approximate weight of an extractor fan is 1.1 kilograms (Airflow, 2016). No LCI data was available for this appliance. Hence an open source repository that identifies a schematic breakdown of an extractor fan is used, alongside the figures established during the tear down study. Universal Fans are a manufacturer of many extractor fans. One specific type of fan is selected for analysis which is considered a good representation as the other models appear to be very similar in construction. The materials that form the extractor fan are assumed based on the exploded image (see figure 5.3) (Universal Fans, 2016).

The relatively simple appliance construction, depicted in figure 5.3 suggests that there is not a very complicated mix of materials found in an extractor fan. The assumption of the material

quantities based on the total weight of the appliance; fifty per cent steel, thirty per cent plastic, ten per cent aluminium and galvanised steel. These are based on the tear down study and the total weight of an extractor fan established earlier in table 5.1. The material quantities used in the LCA for an extractor fan are identified in table 5.7.

<i>Materials</i>	<i>Weights (kg)</i>
plastic - general	0.33
Steel - general	0.55
Aluminium, virgin	0.11
galvanised steel	0.11
Metal (Fixing screws)	0.0041
Rubber	0.011
<i>Table 5.7: Extractor fan material quantities.</i>	

5.5.6 Heated fish tank

Due to the various life spans speculated about by manufacturers, fish tank owners and retailers (Living Reefs, 2017; PetPlace, 2017; Michigan Reefers, 2017), the life span of a typical heated fish tank is assumed to be twenty years based on the life of the materials of which it is composed. The weight of a fish tank, filter and heater are established from manufacturers, approximately 5.38 kilograms (Sharpe, 2016; Hidom, 2016; Aquazonic, 2016). Newton (2016) outlines the basic materials with which a fish tank is constructed (Newton, 2016):

- Acrylic
- Lighting
- Glass
- Silicon

Based on the tear down study of a fish tank heater, an assumption is made that this heater has similar material quantities as those found in a cupboard heater. As observed in both the tear down study and specifications from Sharpe, (2016); Hidom (2016); and Aquazonic, (2016), fish tanks usually have inbuilt lamps in the lid so it is assumed that there is one compact fluorescent portable lamp with the same LCI as identified in the *lighting appliances* section below. There are some variations to this based on the larger tanks sizes available in the market, but for the purposes of this study, these are omitted. The filter motor is constructed from the following materials as identified by Electrical Engineering; copper, rubber, steel and plastic (Electrical Engineering, 2011). The motor quantities are assumed to be the same as the quantities used in the waste master motor. The rest of the major materials are assumed to equal the total weight

remaining, totalling 5.38 kilograms. See table 5.8 for final material quantities identified for the heated fish tank.

<i>Materials</i>	<i>Weights (kg)</i>
PVC - general	0.016
plastic - general	0.35
Copper (Wiring)	0.082
Silicon	0.05
Iron	0.002
Manganese	0.002
Stainless steel	0.5
copper virgin	0.028
Steel	1
Glass, toughened	3
Glass - float	0.3
Iron	0.0005
Aluminium, virgin	0.0000133
cement - General	0.00284
plastic - general	0.00993
Silicon	0.01224
Mercury	0.0000025
argon	0.00031
<i>Table 5.8: Heated fish tank material quantities.</i>	

5.6 Entertainment appliances

5.6.1 Television

Wenzel et al. (2001) wrote a book titled “*Environmental Assessment of Products*”. The study investigated the relationship between environmental assessment and product development, discussing how these two topic areas act together particularly when assessing new product development. They undertook five case studies of different electronic appliances to assess usage, life span and materials. The life span of a television was identified as ten years and the following LCI was identified (see table 5.9) (Wenzel et al., 2001, p. 471). The relatively complex components found in a television during the tear down study made identification of over half the materials impracticable. Hence, the comprehensive LCI data set established by Wenzel et al (2001) is cited for the LCA in this study although clearly it relates to a cathode ray television, given the date and the weight of glass in table 5.9.

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium, virgin	0.33
copper virgin	0.92
Glass, toughened	24.55
Iron	2.58
Lead Virgin	0.12
Nickel	0.53

Sealant epoxide Resin	0.7
plastic - general	13

Table 5.9: Television LCI (Wenzel et al., 2001, p. 471).

5.6.2 Video, computer and separate radio cassette

As identified earlier in section 5.2, an article titled “*Contribution to Resource Conservation by Reuse of Electrical and Electronic Household Appliances*” established several valuable LCI data sets for several household appliances (Truttmann and Rechberger, 2006). The study investigated the relationship between resource conservation, the production phase and energy consumption in an in-depth examination of eight electronic appliances, six of which were identified in the HEEP data:

- Computer (life span of two years)
- Video player (life span of eight years)
- Separate radio cassette (life span of three years)
- Refrigerator (life span of ten years)
- Microwave (life span of ten years)

Only the computer, video games player, video and separate radio cassette will be presented here in the *Entertainment Appliances* section, while the other two appliances are presented below in the *Kitchen and Cooking Appliances* section.

<i>Materials</i>	<i>Weights (kg)</i>
ABS	2.54
High Impact Polystyrene	1.68
Low Density Polyethylene (LDPE) Resin	1.81
Glass, toughened	6.98
Lead Virgin	2.54
Steel Virgin	9.07
Aluminium, virgin	3.04
Metal (Fixing screws)	1.04

Table 5.10: Computer/video games player LCI (Truttmann and Rechberger, 2006).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	2.5
copper virgin	0.3
Aluminium, virgin	0.33
plastic - general	1.13
Lead Virgin	0.74

Table 5.11: Video player LCI (Truttmann and Rechberger, 2006).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	1.042
Copper (Wiring)	0.082
Aluminium, virgin	0.138
plastic - general	0.804
Iron	0.472
PVC - general	0.006
paper	0.00025

Table 5.12: Separate radio cassette LCI (Truttmann and Rechberger, 2006).

5.6.3 Stereo Sound System

The life span of a stereo sound system was identified as three years (Truttmann and Rechberger, 2006). “Explain That Stuff” and “Made How” are two open source repositories used here for the comparison with the tear down study. Both repositories identify appliance assembly, manufacture and component information, these identified the following raw materials found in a stereo (Explain That Stuff, 2016; Made How, 2016b):

- Paper
- Steel
- Iron
- Magnet
- Rubber
- Aluminium
- Plastic

The materials that form the stereo sound system are assumed to be the same as the video player based on the materials identified above and the size of the appliance. A manufacturer of stereo sound systems, Logitech, identified an appliance weight of nine kilograms (Logitech, 2016). The steel, aluminium and plastic materials in the stereo are assumed to weigh 1.5 times those used in a video player based on the weight of materials found in the tear down study. There is also an element of paper found in the speakers, which is assumed to weigh 0.9 grams. The leftover weight of the stereo sound system is assumed to be the iron components. These material quantities are shown in table 5.13.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	3.75
Copper (Wiring)	0.082
Aluminium, virgin	0.495
plastic - general	2.895
Iron	1.7
PVC	0.006
paper	0.0009

Table 5.13: Stereo sound system material quantities.

5.6.4 Television decoder

Truttmann and Rechberger (2006) also identified the life span of a television decoder as five years (Truttmann and Rechberger, 2006). Based on the tear down study the television decoder is assumed to be similar in assembly, construction and size as a video player. Therefore, the material quantities that form a decoder are assumed to be the same as the video player (see table 5.14). There were very minor differences found between materials in the tear down study of the television decoder and video player. Except for a miniature motor used in a video player, most other components including the size of the circuit board were approximately the same size and weight.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	2.5
copper virgin	0.3
Aluminium, virgin	0.33
plastic - general	1.13
Lead Virgin	0.74
<i>Table 5.14: Television decoder material quantities.</i>	

5.7 Washing and drying appliances

5.7.1 Iron

Mezek et al. (2005) undertook a study titled “*An Environmentally Friendly Iron?*” at the Dartmouth Thayer School of Engineering. The study investigated the environmental effects of an iron by means of a life cycle assessment of the appliance. The life span of an iron was identified as four years. The study included the disassembly of an iron to ascertain a life cycle inventory as depicted in table 5.15 (Mezek et al., 2005, p. 8). Some of the housing materials found in the tear down study were atypical when compared to the material found in Mezek et al. However, the figures from Mezek et al. are used here as the tear down study did a breakdown of a thirty-year-old iron.

<i>Materials</i>	<i>Weights (kg)</i>
Plastic	0.411
Steel	0.519
Copper (Wiring)	0.082
Aluminium, virgin	0.038
PVC	0.006
Fabric	0.016
<i>Table 5.15: Iron LCI (Mezek et al., 2005, p. 8).</i>	

5.7.2 Dishwasher

The LCI of a dishwasher is established using figures sourced the study undertaken at the Carnegie Mellon University, as discussed earlier in this chapter. Nearly all materials are the same as those identified in the tear down study. The sole difference between the tear down study and the Carnegie Mellon University data set is the larger size of the water pump found in the dishwasher disassembled in the tear down. This is attributed to the age of the dishwasher used in the tear down study. Hence, the LCI of a dishwasher is based on the Carnegie Mellon University data set and is presented below.

<i>Materials</i>	<i>Weights (kg)</i>
Ceramics - General	3.25
Fibreglass	0.15
Metal (Fixing screws)	4.986
plastic - general	4.118
Rubber	0.511
Stainless steel	1.865
Steel Virgin	5.351

Table 5.16: Dishwasher LCI (Gaudio et al., 2009).

5.7.3 Washing machine

A report titled “*Washing Machine*” by Bourrier et al. (2011) detailed a full life cycle assessment of two washing machines. A washing machine manufactured in 2005 was compared to a washing machine that was manufactured in 2011. The design, energy and overall efficiency of each machine was considered in the life cycle assessment. Essentially, the 2011 model had a lower operational usage, whereas the 2005 machine had a lower production impact. The LCI data set of the 2011 washing machine, established during this study, is presented in table 5.17 (Bourrier, et al., 2011, p. 13).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	25.11
Polypropylene, Orientated Film	16.83
Stainless steel	5.69
Cast Iron	9.28
MDF	2.31
Glass, toughened	2.39
General Polyethylene	0.56
Rubber	1.94
copper virgin	1.68
Aluminium - Virgin	1.33
Ceramics - General	0.53
Hardboard	0.47
Glass, float	0.02

Table 5.17: Washing machine LCI (Bourrier, et al., 2011, p. 13).

5.7.4 Tumble dryer

The life span of a tumble dryer is established by the ATD Home Inspection database. This source identified a thirteen-year life span (ATD, 2016a). No open source LCI data is available for this appliance, therefore the tear down study is compared with the washing machine and dishwasher. This comparison details any possible similarities to the tumble dryer. The tear down study established that much like an oven the tumble dryer has an element of insulation because the appliance uses a heated cylinder to dry clothing. An educational institute undertook a study titled *“Practical Guidelines on How to Save Energy at Home”*. The tumble dryer was one of the appliances that was analysed. The following assembly diagram was identified, describing the materials and components (North-West University Yunibesiti Ya Bokone-Bophirima Noordwes-Universiteit, 2016).

Figure 5.4: Cut away isometric view of a tumble dryer (North-West University Yunibesiti Ya Bokone-Bophirima Noordwes-Universiteit, 2016).

The weight of a tumble dryer was estimated at forty-nine kilograms (Bossert and Waber, 2001). The material quantity of plastic is assumed to be the same as that found in a dishwasher. The quantity of steel is assumed to be relative to the washing machine in terms of weight. The tumble dryer is assumed to have the same amount of insulation as an oven. The quantity of rubber is assumed to be 0.5 kilograms in total because it forms seals on the door and motor. The open source repository, Explain That Stuff, identified that heating elements are typically formed from nickel and chromium (Explain That Stuff, 2009). The heating element used to heat

the air is assumed to be created from equal parts of chromium and nickel and weighing 2.45 kilograms respectively, relative to the total weight of the tumble dryer. The amount of fixing screws is assumed to weigh 0.5 kilograms. A small element of ceramic is assumed to form the construction of the tumble dryer based on the tear down study figures. Plastic and stainless steel are assumed to form the rest of the weight of the appliance. Stainless steel is used to form the outside structure of the tumble dryer, more weight is allocated to this material (see table 5.18).

<i>Materials</i>	<i>Weights (kg)</i>
Ceramics - General	3.25
Fibreglass	2.45
Metal (Fixing screws)	0.5
plastic - general	4.118
Stainless steel	14
Steel Virgin	18
Insulation, fibreglass	1.2
Nickel 8	2.45
Chromium	2.45
Rubber	0.5
Copper (Wiring)	0.082
<i>Table 5.18: Tumble dryer material quantities.</i>	

5.7.5 Cabinet dryer

A part supplier for cabinet dryers identified similar parts and materials to the tumble dryer. The online repository details each part of the cabinet dryer through three-dimensional figures and pictures (Sears Parts Direct, 2017) (see figure 5.5).

Figure 5.5: Parts diagram of a cabinet dryer (Sear Parts Direct, 2017).

The life span of a cabinet dryer is estimated at thirteen years like that of a tumble dryer. Trifate Appliances, a manufacturer of cabinet dryers, identified the weight of an average cabinet dryer is 3.7 kilograms, albeit this version has a fabric enclosure, not metal as shown in figure 5.5. (Trifate Appliances, 2016). All the material quantities are assumed to be the same as the tumble dryer but relative to the total weight difference between the two appliances (see table 5.19).

<i>Materials</i>	<i>Weights (kg)</i>
Ceramics - General	0.246
Fibreglass	0.186
Metal (Fixing screws)	0.038
plastic - general	0.312
Rubber	1.061
Stainless steel	1.369
Steel Virgin	0.091
Insulation, fibreglass	0.186
Nickel 8	0.186
Chromium	0.038
plastic - general	0.006
Copper (Wiring)	0.006
<i>Table 5.19: Cabinet dryer material quantities.</i>	

5.8 Kitchen and cooking appliances

5.8.1 Refrigerator

As discussed earlier, Truttmann and Rechberger (2006) identified material and energy balances of eight electronic appliances. This included an extensive analysis of refrigerators. Because of this comprehensive break down, the tear down study did not include data for a combination fridge-freezer or a deep freezer. The refrigerator LCI data set established by Truttmann and Rechberger (2006), is presented in table 5.20.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	21.5
Iron	2
copper virgin	2
plastic - general	22
Toughened Glass	0.5
Aluminium, virgin	1
Lead Virgin	1
<i>Table 5.20: Refrigerator LCI (Truttmann and Rechberger, 2006).</i>	

5.8.2 Combination fridge-freezer

Horie (2004) wrote a thesis titled “Life Cycle Optimization of Household Refrigerator-Freezer Replacement”. The study identified average energy consumption and replacement cycles of

refrigerators in the United States. Horie (2004) used consumer reports and manufacturer data to conduct a life cycle assessment establishing the cost of operating refrigerators. The study identified the life span of both a combination fridge-freezer and a deep freezer as fourteen years (Horie, 2004, p. 3). The LCA software tool SimaPro 5.1 identified two available datasets; an average 1997 U.S top/bottom refrigerator 20.5 ft³ (580.5L), and a typical Japanese 400L freezer (Horie, 2004, pp. 45-47). In order to establish the relevance of this study to New Zealand households, two New Zealand whiteware suppliers (Harvey Norman and Noel Leeming) are used to corroborate the average size of combination fridge-freezers and freezers in New Zealand (Harvey Norman, 2017a; Noel Leeming, 2017). The following appliance sizes were identified.

<i>Appliance</i>	<i>Harvey Norman</i>	<i>Noel Leeming</i>
Combination fridge-freezer	227 L – 725 L (589.5 L average)	215 L – 710 L (570 L average)
Freezer	143 L – 669 L (478 L average)	140 L – 700 L (490 L average)
<i>Table 5.21: Average size of New Zealand combination fridge-freezers and freezers.</i>		

Table 5.21 identifies that based on the various sizes of refrigerators and freezers currently available in the New Zealand market, the average refrigerator and freezer sizes used in Horie (2004) are appropriate to use in this analysis. Horie (2004) identified the following LCIs (tables twenty-two and twenty-three) (Horie, 2004, pp. 45-46).

<i>Materials</i>	<i>Weights (kg)</i>
Steel	47.55
Cast Iron	4.56
Aluminium, virgin	2.11
Copper tube	2.87
Metal (Fixing screws)	0.25
Rubber	0.17
Fabric	0.08
Plastic	23.48
Insulation, fibreglass	0.08
Glass, float	2.87
Refrigerant fluid 8	0.08
Shell 320 oil 8	0.17
<i>Table 5.22: Combination fridge-freezer LCI (Horie, 2004, p. 45).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	38.22
Copper tube	1.68
Copper (Wiring)	1.56
Aluminium, virgin	1.07
Metal (Fixing screws)	0.07
ABS	61.9
PVC General	2.2
plastic - general	25.08

Mastic Sealant	1.55
Shell 320 oil 8	0.24
Refrigerant fluid 8	0.18
Glass, toughened	0.24
<i>Table 5.23: Deep freezer LCI (Horie, 2004, p. 46).</i>	

5.8.3 Toaster

A conference paper titled “*Life Cycle Networks*” (F. L. Krause and G. Seliger 1997) is used for the LCI of a toaster. this study included an investigation of product structure and disassembly, in order to theorise possible efficient recycling methods to mitigate waste produced (F. L. Krause and G. Seliger 1997). The life span of a toaster was identified as six years. This study identified that a conventional toaster “*consists of 26 different parts made of steel, aluminium, copper, plastic and paper and also one circuit-board*” (F. L. Krause and G. Seliger 1997, p. 244). The detailed LCI for this toaster is shown in table 5.24 (Krause and Seliger, 1997, p. 244).

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	0.62
Aluminium, virgin	0.02
copper virgin	0.06
plastic - general	0.4
<i>Table 5.24: Toaster LCI (Krause and Seliger, 1997, p. 244).</i>	

The plastic components found in the tear down study findings were heavier as the entire housing of the specific toaster used in the tear down was made entirely of plastic. As shown in figure 5.6.

Figure 5.6: Toaster tear down study, the plastic housing removed was the largest single material in this toaster example.

5.8.4 Electric jug (kettle)

Huisman et al. (2007) identified the life span of an electric jug as three years, and the weight of an electric jug as one kilogram. The extensive data collected in this study is reliable because one hundred and eighty-three different contacts were approached for interviews, questionnaires and specific data to gather a reliable data set (Huisman, et al., 2007). However, no LCI data was found for this appliance. The materials that form the electric jug are assumed from an open source repository (Made How, 2016c). “Made How” is an electronic database of assembly and manufacturing information of several household appliances (Made How, 2017). Made How identified the following raw materials used to construct an electric jug:

- Polypropylene plastic
- Stainless steel
- Heating element

The heating element of the kettle is assumed to be formed from the same material and weight as that identified in a coffee maker (copper tubing). The kettle has two main components, the base and the body. These are assumed to be made of approximately fifteen per cent injected polypropylene for the base, handle and lip, and approximately eighty per cent stainless steel for the body of the electrical jug. The estimated material quantities are identified in table 5.25.

<i>Materials</i>	<i>Weights (kg)</i>
Polypropylene, Injection Moulding	0.15
Stainless steel	0.8
PVC	0.006
Copper tube	0.055
Copper (Wiring)	0.082

Table 5.25: Electric jug (kettle) material quantities.

5.8.5 Coffee maker, food processor and mixer

The LCI data sets for a coffee maker, a food processor and a mixer are sourced from the Carnegie Mellon University (2014) study identified earlier in this chapter. These are listed in tables 5.26, 5.27 and 5.28 below.

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium, virgin	0.255
paper	0.007
copper virgin	0.055
Glass, toughened	0.33
plastic - general	0.88
Rubber	0.034
Steel Virgin	0.018

Table 5.26: Coffee maker LCI (Neffa et al., 2014).

Materials	Weights (kg)
Aluminium, virgin	0.046
copper virgin	0.028
Brass virgin	0.037
Bronze	0.001
Fibreglass	0.003
plastic - general	0.962
Rubber	0.012
Stainless steel	0.499

Table 5.27: Food processor LCI (Cone et al., 2007).

Materials	Weights (kg)
Steel	0.537
Metal (Fixing screws)	0.0036
plastic - general	0.5345
Rubber	0.032
Silicon	0.021
Glass, toughened	1.286
MDF	0.001
Brass virgin	0.01

Table 5.28: Mixer LCI (Weisburgh et al., 2011).

5.8.6 Bread maker

An article titled “*Bread Machine Reviews 2016: Best Bread Machines*” presented the results of a study that compared several bread makers, looking at cost, weight and warranty length. The typical warranty length of a bread maker was identified as two years. Three bread machines were compared and a range of weight was estimated between 12.3 and 22.1 pounds (six to ten kilograms) (Bread Machine Pros, 2016). An average weight of 8.5 kilograms was selected for the bread maker. Explain That Stuff identified that a bread maker is similar in functionality and construction to an oven (Explain That Stuff, 2008a). The food processor and oven material quantities discussed earlier are scrutinised in detail for any similarities. The open source repository identified that the following components form a bread maker (materials are assumed in brackets based on what was found in the tear down study):

- Heating element (nickel and chromium)
- Electric motor (copper, rubber, steel and plastic)
- Metal paddle (steel)
- Waterproof seal (rubber)
- Baking tin (aluminium)
- Plastic outer case

An assumption is made that stainless steel, steel and copper are twice the weights of those in a food processor. The assumption is that two types of plastic are used, general plastic and PVC. The heating element constructed from nickel and chromium is assumed to weigh 0.5 kilograms. Aluminium and plastic form the main materials in this appliance, the weights for these are assumed and distributed across the remaining weight (six kilograms). The resulting material quantities are detailed in table 5.29.

Aluminium, virgin	3
Copper (Wiring)	0.082
plastic - general	3
Stainless steel	1
Steel Virgin	0.4
copper virgin	0.056
PVC General	0.55
Zinc Virgin	0.0018
Nickel 8	0.25
Chromium	0.25

Table 5.29: Bread maker material quantities.

5.8.7 Rice cooker and crock pot

The life span of a rice cooker is identified by Cuckoo (2016), a rice cooker supplier, as four years. An independent quote by Panasonic, a manufacturer of rice cookers (and many other household appliances), identifies a similar life span and the total weight of the appliance at 1.4 kilograms (Panasonic, 2016). However, they do not publicise LCI data. Instead, an open source repository, much like “Explain That Stuff” and “Made How” is sourced. How Stuff Works (2008) identifies the manufacture, assembly process and key components of many household appliances (How Stuff Works, 2008). The material quantities are assumed based on figure 5.7 and the aforementioned total weight figure sourced from Panasonic.

Figure 5.7: Section of a rice cooker detailing the components (How Stuff Works, 2008).

Figure 5.7 depicts the various parts of a generic rice cooker. These parts are described in “how Stuff Works” as:

- Aluminium inner cooking pan;
- Heating plate (chromium and nickel);
- Main body (steel and plastics);
- Glass lid (tempered glass and plastics).

Paint is typically used to coat the inside of a rice cooker bowl (How Stuff Works, 2008). The paint quantity is assumed to be twice the quantity of that used on the cupboard heater. The tear down study identifies that the edges and feet of the rice cooker are made of plastics; the lid is made of glass with a steel frame, and plastic handle; steel and aluminium form the rest of the total weight for the housing. A crockpot is assumed to have the same life span, weight and material quantities as a rice cooker (see table 5.30).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	0.14
Aluminium, virgin	0.7
Paint - General	0.004
copper virgin	0.13
plastic - general	0.04
Glass, toughened	0.33
Chromium	0.1
Nickel	0.1
PVC - general	0.006
<i>Table 5.30: Rice cooker material quantities.</i>	

5.8.8 Microwave

The LCI data set for a microwave is established using the Truttmann and Rechberger (2006) life cycle assessment. The material quantities are based on a twenty-seven litre microwave. The tear down study revealed almost identical material weights for a seven-year-old (2010 model) thirty-two litre microwave. This may suggest that newer microwaves incorporate lighter weight construction or the physical size of the microwave has minimal effect on the amount of materials used in its manufacture. The microwave LCI figures established by Truttmann and Rechberger are presented in table 5.31.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	16.4
copper virgin	0.897
Aluminium, virgin	0.897
plastic - general	0.874

Toughened Glass	1.61
Lead Virgin	2.323

Table 5.31: Microwave LCI (Truttmann and Rechberger, 2006).

5.8.9 Waste master (or waste disposal unit)

An average waste master unit has a life span of twelve years (ATD, 2016a) and an average weight of 6.16 kilograms (InSinkErator, 2016). No LCI data could be sourced from open source repositories for a waste master, therefore the materials quantities found in a food processor are scrutinised for possible material similarities. A comparison between the waste master tear down study and a large 100-watt food processor established that these two appliances have a similar size and have similar components.

Figure 5.8: Cut-away section of a waste maser (Franke, undated).

In order to validate these assumptions, all components are compared to a cross sectional schematic used by fitting retailers that identifies all the parts found in an average waste master (Lowe's, 2016) and figure 5.8 (Franke, undated):

- PVC pipe
- Rubber hose and gaskets
- Plastic
- Steel flange etc.
- Screws

- Motor
- Magnets
- Stainless steel
- Glass
- Nylon
- Copper
- Insulation (fabric)

It is assumed that the materials that make up the waste master motor are the same as a generic appliance motor established earlier in this chapter using the figures from Electrical Engineering (2011). “Made How” identified that magnets are typically formed from iron (Made How, 2016d). The magnets, disassembled in the tear down study and in those depicted in the motor in figure 5.8, are reasonably large. These were weighed at just under 0.5 kilograms. The complex construction of a waste master is the main reason the quantity of metal fixings in this compact appliance is relatively bigger in comparison to a food processor. The copper quantity is assumed to be the same as that in a food processor. An assumption is made that the steel quantity is three times that of the food processor because the blades of the waste master are stronger and more complex when compared, these could not be dismantled entirely in the tear down study. The rest of the materials are assumed based on the remaining weight of the appliance (see table 5.32).

<i>Materials</i>	<i>Weights (kg)</i>
copper virgin	0.028
Copper (Wiring)	0.082
plastic - general	1.5708
Rubber	0.01
Steel Virgin	1.497
Iron	0.5113
PVC Pipe	2
Aluminium, virgin	0.1232
Glass, float	0.006
Cotton, Fabric	0.00062
Nylon (Polyamide) 6 Polymer	0.1848
Metal (Fixing screws)	0.006

Table 5.32: Waste master material quantities.

5.8.10 Range hood

Identified at the beginning of this chapter, ATD (2016a) catalogues a comprehensive list of household appliances, identifying average usage and life spans. ATD identified the life span of a range hood as fourteen years (ATD, 2016a). This study examined a wide range of range hoods

and induction hobs, specifically identifying a list of materials for each as well as their material quantities. The study titled “*Cost Breakdown Analysis: A study of product costs in kitchen appliances at IKEA of Sweden*” (Asking and Gustavsson, 2011) investigated the costs attributed to the manufacture and distribution of these appliances and meticulously documented the raw materials used. Asking and Gustavsson examined the following models:

1. Range hoods
 - Lagan
 - Luftig
 - Dåtíð
 - Framtíð
 - Nutíð
2. Induction hobs
 - Framtíð
 - Nutíð

With a goal of identifying key the cost drivers for these products, the purpose of the study was to reduce the cost of manufacture. Data for manufacturing procedures and materials use was collected by conducting a series of surveys and visiting the production plants. Due to the wide range of appliances covered by Asking and Gustavsson, no tear down study was conducted for a range hood in this study. Instead, the LCI data set for a representative range hood is established using figures from Asking and Gustavsson. These are shown in figures nine and ten. (Asking and Gustavsson, 2011, p. 53).

Table 17 - Steel composition		
	Hood 1	Hood 3
Stainless steel	99,26%	5,88%
Carbon steel	0,74%	91,76%
Aluminium		0,71%
Galvanized steel		1,65%
Total	100,00%	100,00%

Figure 5.9: Table 17 identified the steel types used in two range hoods (Asking and Gustavsson, 2011, p. 53).

Table 18 - Relative material cost for hoods

	Hood 1	Chimney for Hood 1	Hood 2	Hood 3	Hood 4
Plastic	6,33%		3,47%	4,44%	9,19%
Steel	37,46%	99,38%	36,24%	15,58%	36,67%
Grease filter	5,30%		1,93%	6,96%	6,69%
Motor (scroll)	44,96%		45,03%	60,28%	42,66%
Electrical comp.	2,24%			2,75%	1,45%
Lightning comp.	0,79%		8,77%	1,06%	1,02%
Cables	2,71%		1,24%	2,24%	2,16%
Screws	0,20%	0,62%	0,34%	0,46%	0,17%
Other			2,98%	6,24%	
Total	100,00%	100,00%	100,00%	100,00%	100,00%

Figure 5.10: Table 18 identifies the relative material costs for four range hoods (Asking and Gustavsson, 2011, p. 53).

Figure 5.9 identifies that there is a lighting component in the construction of a range hood. Here an assumption is made that this appliance has one fixed incandescent lamp with the same material quantities as identified in the *Lighting* section below. Installation instructions produced by the manufacturer Fisher and Paykel identified the weight of a range hood as 8.2 kilograms (Fisher and Paykel, 2013). The range hood has screws holding the components together. Based on the LCI data set established by Asking and Gustavsson (2011, p. 53) an assumption is made that these screws weigh 8.2 grams. In order to understand and distinguish all the smaller complex material specifications, supplier information is used. As a result, three key materials are identified in the makeup of grease filter trays; aluminium, carbon and charcoal (Big Brands Online, 2016). For this study, it is assumed that the filters are made of aluminium and that there is some aluminium in the composition of the range hood totalling an estimated 0.5 kilograms.

Figure 5.9 details the steel composition of typical range hoods. Figures from hood one are used instead of hood three. This selection is made based on a “Reliance Foundry” study that identifies that the use of stainless steel appliances is more common in wet areas like a kitchen (Reliance Foundry, 2017).

Figure 5.10 identifies that hood one has 0.74 per cent of carbon steel in relation to the amount of stainless steel. The steel quantity is assumed to equal 0.4 kilograms in total, including steel in the motor. The components in the motor are established based on the Electrical Engineering (2011) data set identified earlier in this chapter.

The range hood fan is assumed to be constructed from plastic, this component and the plastic included in the motor are assumed to weigh 0.65 kilograms. The stainless-steel quantity is assumed to be 6.5 kilograms to equal a total appliance weight of 8.2 kilograms. The final material quantities are depicted in table 5.33.

<i>Materials</i>	<i>Weights (kg)</i>
plastic - general	0.65
Stainless steel	6.5
Steel - general	0.4
Aluminium, virgin	0.5
Metal (Fixing screws)	0.0082
Copper (Wiring)	0.164
PVC	0.012
Rubber	0.5
Aluminium - Virgin	0.00115
argon	0.0002
Cement, average NZ	0.00145
copper virgin	0.0010375
Glass - float	0.02054
Nickel	0.000084
Tin	0.00015
Titanium virgin	0.00001

Table 5.33: Range hood material quantities.

5.8.11 Stoves and ovens

Jungbluth (1997) compared cooking alternatives by means of Life Cycle Assessment (LCA). A survey was used to investigate how environmental impacts link with household cooking consumption patterns. An LCI was created as part of this LCA. The LCIs of five cooking appliances identified in the HEEP study are presented below (see table 5.34 to 5.37) (Jungbluth, 1997).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	47.601
Glass, toughened	6.642
Aluminium, virgin	0.09963
Paint - General	7.9704
copper virgin	0.19926
insulation - general	1.2177
PVC General	0.13284
Zinc Virgin	0.2214

Table 5.34: Electric range (hob+stove) LCI (Jungbluth, 1997).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	51.61
Glass, toughened	7.2
Aluminium, virgin	0.108
Paint - General	8.64
copper virgin	0.216
Fibreglass	1.32

PVC General	0.144
Zinc Virgin	0.24
<i>Table 5.35: Gas range (either gas or LPG) LCI (Jungbluth, 1997).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	43
Glass, toughened	6
Aluminium, virgin	0.09
Paint - General	7.2
copper virgin	0.18
insulation - general	1.1
PVC General	0.12
Zinc Virgin	0.2
<i>Table 5.36: Electric and gas oven LCI (Jungbluth, 1997).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	150
Glass, toughened	1
Aluminium, virgin	0.1
Paint - General	7.2
copper virgin	0.2
insulation - general	3
PVC General	0.2
Zinc Virgin	0.2
<i>Table 5.37: Wood/Coal range LCI (Jungbluth, 1997).</i>	

5.8.12 Hobs

The electric and gas hob LCIs are sourced from the manufacturer, Samsung (Samsung, 2016). Samsung is a leading global manufacturer of electronics and appliances. Established in 1938, Samsung has decades of experience manufacturing appliances (Samsung, 2017). This is one of the few appliances for which manufacturer's data could be sourced, as recommended by ISO. Samsung identified the life span of electric and gas hobs as ten years. Tables thirty-eight and thirty-nine depict the LCI established for an electric and gas hob.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	4.601
Glass, toughened	0.642
Aluminium, virgin	0.01
Paint - General	0.77
copper virgin	0.019
insulation - general	0.118
PVC General	0.013
Zinc Virgin	0.021
<i>Table 5.38: Electric hobs LCI (Samsung, 2016).</i>	

Materials	Weights (kg)
Steel Virgin	8.6
Glass, toughened	1.2
Aluminium, virgin	0.018
Paint - General	1.44
copper virgin	0.036
insulation - general	0.22
PVC General	0.024
Zinc Virgin	0.04
<i>Table 5.39: Gas hobs (either gas or LPG) LCI (Samsung, 2016).</i>	

The Samsung data set did not include any LCI data set for an induction hob, therefore the article titled “*Life Cycle Assessment of a Domestic Induction Hob: Electronic boards*” is used to identify material quantities for induction hobs (Elduque et al., 2014). This study conducted an LCA of a 7.2kW, four ring induction cooktop. Two databases, Ecoinvent v2.2 and Chalmers CPM LCA database, were used to create the LCA model. In this study, the life span of an induction hob was identified as fifteen years. Elduque et al. also (2014) identified the LCI for an induction hob (see table 5.40).

Materials	Weights kg (% of Appliance weight)
Metal (Fixing screws)	0.0002 (0.04%)
Ceramics - General	0.0004 (0.09%)
Polycarbonate	0.0045 (1.01%)
Aluminium, virgin	0.0229 (5.13%)
Steel	0.0434 (9.73%)
Tin	0.0594 (13.32%)
copper virgin	0.3153 (70.68%)
<i>Table 5.40: Induction hobs LCI (Elduque et al., 2014).</i>	

In order to validate these figures, a tear down study was conducted on a single induction cooking ring (separate portable unit). The components identified in this tear down study included a power cable connected to the circuit board which is connected to an induction coil and a controls circuit board. These three components are housed in a plastic case fitted with a plastic cooling fan in the base.

Figure 5.11: Induction hob tear down study.

Since the appliance used in this tear down study was a smaller single unit, all the materials were weighed and represented as percentages of the total weight of the appliance. The material weights are presented in table 5.41.

<i>Materials</i>	<i>Weights (%)</i>
Metal (Fixing screws)	0.04%
Ceramics - General	0.08%
Plastics	2.31%
Aluminium, virgin	5.03%
Steel	7.82%
Tin	12.71%
copper virgin	72.01%
<i>Table 5.41: Tear down study Induction burner LCI (Elduque et al., 2014).</i>	

The relative breakdown in the tear down study is almost identical to the figures established identified by Elduque et al. The biggest variations are in the percentages of steel and copper which are materials used for the induction coil and electronic parts of the circuits. Here the relative weight variation is expected as a hob would have different sized rings that would skew these figures when compared to the single unit. The other difference in material proportions is the greater percentage of plastic used in the portable unit. This is again an expected variation as the portable unit is completely closed off, whereas the hob would not have a plastic closure all around it. Accounting for these minor variations the LCI data set established by Elduque et al. is considered a good representative data set to use for this LCA.

5.8.13 Bench top mini-oven

A bench top mini oven is assumed to have the same life span and materials as the electric oven. The weight of an electric oven was identified as fifty-seven kilograms (see section 5.8.11), while the weight of a mini bench top oven was ten kilograms (Breville, undated). Based on this data the materials quantities are assumed to be a sixth of the LCI established for a full-sized oven. These final material quantities depicted in table 5.42, these are adjusted to suit the weight difference between the two appliances.

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	7.428
Glass, toughened	1.036
Aluminium, virgin	0.016
Paint - General	1.244
copper virgin	0.031
insulation - general	0.191
PVC General	0.021
Zinc Virgin	0.035
<i>Table 5.42: Mini bench top oven material quantities.</i>	

5.8.14 LPG barbeque

Consumer New Zealand identified the life span of LPG barbeques is approximately four years (Consumer NZ, undated). In order to establish a representative weight manufacturers' information was sourced. This identified that a typical LPG barbeque weighs approximately sixty-four kilograms (BBQs Direct, 2016). A break down study by "Design technology" (undated) identified the manufacturing components used in the construction of an LPG barbeque are (Design Technology, undated):

- Steel
- Aluminium
- Stainless steel
- Nylon handles, wheels and knobs

The Design technology break down study did not include the additional materials not manufactured with the barbeque unit. These are the universal gas fittings that are often sold with the barbeque in retail stores but not necessarily manufactured together. Instead, the components of these fittings were established using figures from Gasmate (2016):

- Rubber
- Metal fixing screws

Based on the manufacturer's specification of appliance components and total weights the following assumptions are made considering the tear down study figures. The quantity of handles, wheels and knobs and lightweight and heat resistant nylon fittings (Design Technology, undated) is assumed to be three kilograms. The rubber hose that connects the LPG bottle to the barbeque is assumed to weigh 0.5 kilograms. Materials in the housing consist of aluminium and stainless steel. There are some much older barbeques that can be made of iron, but these are omitted in this LCA based on current market availability. (Harvey Norman, 2017c; Noel Leeming, 2017). The LCI data set established for a LPG barbeque is listed in table 5.43.

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	48
Nylon (Polyamide) 6 Polymer	3
Aluminium, virgin	5
Steel - general	7
Rubber	0.5
Metal (Fixing screws)	0.082
<i>Table 5.43: LPG barbeque material quantities.</i>	

5.8.15 Charcoal barbeque

A manufacturer, Weber, identified the product warranty of a charcoal barbeque to range from five to ten years. In order to represent this range of warranties, a seven-year life span is selected for this appliance. Weber also identified the weight of an average charcoal barbeque to be 14.4 kilograms (Weber, 2016). The range hood and LPG barbeque are scrutinised in detail for any possible similarities to the charcoal barbeque. A manufacturing video of a charcoal barbeque identified the following raw materials and components (Design Technology, undated):

- Ceramic coating
- Stainless steel cast iron
- Nylon handles, wheels and knobs
- Paint
- Fixing screws
- Aluminium damper

The quantity of metal fixing screws in a charcoal barbeque is assumed based on the amount of screws in a range hood. The appliances are a similar size and constructed in a similar way. The quantity of a coating of paint and ceramic are assumed to be four times those of a rice cooker. The handles and wheels are constructed from nylon and are assumed to weigh two kilograms. The leftover weight is assumed to be distributed between steel and stainless steel, steel being that of the body and weighing more than the light stainless-steel legs (see table 5.44).

<i>Materials</i>	<i>Weights (kg)</i>
Nylon (Polyamide) 6 Polymer	2
Stainless steel	4
Steel - general	8
Metal (Fixing screws)	0.082
Paint - General	0.008
Aluminium, virgin	0.01
Ceramics - General	0.008

Table 5.44: Charcoal barbeque material quantities.

5.8.16 Electric barbeque

Weber also identified that an electric grill has a product warranty between two and five years. A four-year life span is selected for this appliance (Weber, 2017). Davis (2012) undertook a study to compare electric barbeques. this study compared five different electric grills and tested

the assembly and cooking ability of each model. As per the ISO 14044, although Davis (2012) identifies the brands compared, these are omitted here and are instead referred to as:

<i>Brand</i>	<i>Weight (pounds)</i>
E-BBQ -1	12kg
E-BBQ -2	23kg
E-BBQ -3	18kg
E-BBQ -4	8kg
E-BBQ -5	14kg

Table 5.45: Review of five electric

Of these five examples, E-BBQ-3 is selected for this study as this is the average weight of the barbeques compared, weighing approximately eighteen kilograms. Davis (2012) did not identify any other LCI data other than the cooking plates, which are said to be typically formed from cast iron. However, “Diffen” (2016), a manufacturer of electric barbeques identified that an electric barbeque is similar to an indoor electric grill plate in that it has a Teflon cooking surface rather than a gas flame and grills; and the plates use heating elements to cook the food (Diffen, 2016). Since there is no readily available embodied energy data for a Teflon layer, plastic is chosen for this analysis because Teflon is a plastic polymer (Chemours, 2013). The quantity is assumed to be four grams, like the coating on a rice cooker (section 5.8.7). The quantity of metal fixing screws in an electric barbeque is assumed, based on the amount of screws in a range hood. The appliances are a similar size and constructed in a similar way. The heating element is assumed to be constructed from an equal amount of nickel and chromium, similar to the dehumidifier, weighing 0.7 kilograms respectively. Based on the tear down study the cast iron plates for a generic barbeque are assumed to weigh approximately four kilograms. The weight of the last two materials, aluminium and stainless steel are assumed to be two kilograms and eight kilograms to equal a total weight of 18.1 kilograms (see table 5.46).

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	8
Nylon (Polyamide) 6 Polymer	3
Aluminium, virgin	2
Copper (Wiring)	0.082
PVC - general	0.006
Metal (Fixing screws)	0.082
plastic - general	0.004
Nickel 8	0.7
Chromium	0.7
Cast iron	4

Table 5.46: Electric barbeque material quantities.

5.8.17 Electric fry pan

A fry pan was assumed to have the same life span and materials as the electric barbeque. The weight of an electric barbeque was identified as 18.5 kilograms while the weight of a fry pan was identified as 5.1 kilograms (Sunbeam, 2017). This is a scenario in which a gram of an electric barbeque is considered to equal a gram of electric fry pan. The final material quantities depicted in table 5.47 were adjusted to suit the weight difference between the two appliances.

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	2.197
Nylon (Polyamide) 6 Polymer	0.824
Aluminium, virgin	0.549
Copper (Wiring)	0.082
PVC - general	0.006
Metal (Fixing screws)	0.023
plastic - general	0.001
Nickel 8	0.192
Cast Iron	1.098
Chromium	0.192
<i>Table 5.47: Electric fry pan material quantities.</i>	

5.9 Space heating appliances

5.9.1 Electric blanket

Chen et al. (2013) wrote a report titled “*An Investigation into the Replacement of Personal Heaters with Electrically Heated Blankets*”. Twenty-two staff members were interviewed at the University of British Columbia. Each staff member was provided with an electrically heated throw to replace their personal heaters. Essentially the purpose of this study was to establish the viability of reducing the power consumption of personal heaters throughout the university. This identified a five-year manufacturer’s warranty for the electric blankets used in the study (Chen et al., 2013). A manufacturer, Biddeford, identified the weight of an electric blanket as five pounds, which equates to around two kilograms (Biddeford, 2016). The materials that form the electric blanket are assumed based on an online repository and the construction of a heated towel rail, as the appliance has similar functionality and assembly. The following components and materials were identified (Made How, 2016e):

- Woven cloth (polyester and acrylic)
- Heating element (metal alloy)
- Bedside control (plastic)
- Power cord (plastic)

The heating element quantity in the electric blanket is assumed to be copper, like the heating element in a towel rail. The padding and synthetic fabric used to form the blanket are assumed to be constructed from cotton. The plastic control is assumed to weigh 0.2 kilograms. The cotton padding and fabric are assumed to equally form the rest of the weight of the blanket, totalling two kilograms. The final material quantities are detailed in table 5.48. The weight and material quantities of the double electric blanket are assumed to be twice that of the single electric blanket.

<i>Materials</i>	<i>Weights (kg)</i>
Cotton, Fabric	0.7
Cotton, Padding	0.7
PVC - general	0.006
copper virgin	0.4
plastic - general	0.2
Copper (Wiring)	0.082
<i>Table 5.48: Single electric blanket material quantities.</i>	

5.9.2 Fan and radiator heaters

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) produced an equipment life expectancy chart, which lists the life expectancy of heating equipment. ASHRAE is the industry organization that sets the standards and guidelines for most all HVAC-R equipment. The data presented in this chart identified the median life expectancies of various heating appliances used in both residential housing and commercial buildings. The expected life span of household radiant heaters was established by ASHRAE as ten years (ASHRAE, 2013). The portable fan heater, wall fan heater (bathroom), electric radiator heater, portable electric radiator heater and obsolete radiator heater are assumed to be similar in material construction and life span. an example of a portable fan heater disassembled in the tear down study is depicted here.

Figure 5.12: Tear down study: Portable fan heater.

The following materials are identified based on figure 5.12:

- Plastic (housing and knobs)
- Copper coil (heating element)
- Steel (fixings and fan blade)

One model of a portable fan heater weighs approximately 1.27 kilograms (Impress, 2016). The heating element in a fan heater is assumed to be constructed from copper coils weighing 0.12 kilograms, twice that of the quantity in a toaster (Explain That Stuff, 2009). The body and fan of the heater are constructed from plastic, weighing 0.5 kilograms. An element of steel is assumed to form the rest of the weight. Table 5.49 details the material quantities for a portable fan heater.

<i>Materials</i>	<i>Weights (kg)</i>
Copper virgin	0.12
PVC - general	0.006
Steel	0.2
plastic - general	1
Copper (Wiring)	0.082
<i>Table 5.49: Fan heater material quantities.</i>	

The wall fan heater (bathroom) is assumed to have the same life span, material quantities as a portable fan heater. Essentially the wall fan heater is a vertically mounted portable fan heater. Table 5.50 depicts the final material quantities used in the analysis.

<i>Materials</i>	<i>Weights (kg)</i>
Copper virgin	0.12
PVC - general	0.006
Steel	0.2
plastic - general	1
Copper (Wiring)	0.082
<i>Table 5.50: Wall fan heater (bathroom) material quantities.</i>	

A radiator heater was identified to weigh approximately 3.2 kilograms (Goldair, 2017a). A supplier of radiator heaters identified the material of the heating tubes as quartz with an element of ceramic (Infrared Heaters, 2015). An assumption is made that these tubes weigh 1.5 kilograms in total. The rest of the heater is assumed to be constructed from steel (see table 5.51).

<i>Materials</i>	<i>Weights (kg)</i>
Quartz powder	1.4
Ceramic - general	0.1
PVC - general	0.006
Steel	1.7
Copper (Wiring)	0.082
<i>Table 5.51: Electric radiator heater material quantities.</i>	

The portable radiator heater is assumed to be similar to a radiator heater weighing approximately half as much as a radiator heater (see table 5.52).

<i>Materials</i>	<i>Weights (kg)</i>
Quartz	0.7
Ceramic - general	0.05
PVC - general	0.006
Steel	00.85
Copper (Wiring)	0.082
<i>Table 5.52: Portable electric radiator heater material quantities.</i>	

The obsolete radiator heater was found to weigh approximately ten kilograms (Lifesmart, 2016). Most of the material quantities for the obsolete radiator heater are assumed to be the same as the radiator heater, but relative for the weight difference (see table 5.53).

<i>Materials</i>	<i>Weights (kg)</i>
Quartz	4.3
Ceramic - general	0.3
PVC - general	0.006
Steel	5.3
Copper (Wiring)	0.082
<i>Table 5.53: Obsolete radiator heater material quantities.</i>	

5.9.3 Portable convection heater

A manufacturer, DeLonghi, identified that a typical convection heater weighs around 2.7 kilograms. The heating element is assumed to be made from equal parts of nickel and chromium, weighing 0.3 kilograms each (Explain That Stuff, 2009). The wheels and controls of the heater are assumed to be constructed from plastic and weigh 0.25 kilograms in total. The oil inside the fins of the heater is assumed to weigh 0.8 kilograms. DeLonghi identified that the heater body is constructed from steel and thus forms the leftover majority weight of the appliance (DeLonghi, 2016) (see table 5.54).

<i>Materials</i>	<i>Weights (kg)</i>
Nickel 8	0.3
Chromium	0.3
PVC - general	0.006
Steel	1
plastic - general	0.25
Shell 320 oil 8	0.82
Copper (Wiring)	0.082
<i>Table 5.54: Portable convection heater material quantities.</i>	

5.9.4 Electric panel heater

The fixed electric panel heater has an assumed life of three years as determined by the manufacturers (Dimplex, 2009). All LCI information is directly sourced from the manufacturer (Dimplex, 2009). Hence, the following LCI was identified for a fixed electric panel heater (see table 5.55).

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium, virgin	6.4
Ceramics - General	1.6
Shell 320 oil 8	3.5

Table 5.55: Electric panel heater LCI (Dimplex, 2009).

5.9.5 Portable kerosene heater

The life span of a kerosene heater is assumed to be six years based on the life spans of other heating appliances. The materials of the portable kerosene heater are assumed based on the three-dimensional images in a radiant kerosene heater reference manual (see figure 5.13 to figure 5.16) (Rent-E-Quip, undated).

Figure 5.13: Structure of the wick in a portable kerosene heater (Rent-E-Quip, undated).

Figure 5.14: Burner unit in a portable kerosene heater (Rent-E-Quip, undated).

Figure 5.15: A radiant type portable kerosene heater (Rent-E-Quip, undated).

Figure 5.16: Igniter in a portable kerosene heater (Rent-E-Quip, undated).

The following materials are identified:

- Cotton
- Glass wool thread
- Glass cylinder
- Kerosene
- Steel
- Plastic
- Aluminium
- Iron

As there are no readily available embodied energy figures for kerosene, oil is assumed in place of kerosene. A portable kerosene heater was found to weigh approximately 12.8 kilograms (Dura Heat, 2016). An assumption is made that the fuel weighs 0.3 kilograms in a portable kerosene heater. The structure of the wick is made from cotton and assumed to weigh 0.5 grams. Plastic is assumed to form the handle and part of the structure weighing 1.5 kilograms. The image for the radiator type detailed in the manual showed that the wick and thread are made of glass wool so embodied energy data for fibreglass is chosen for this analysis. Two kilograms

of aluminium is assumed to form some of the parts and the mesh used in front of the burner. The glass cover on the outside that protects the burner is assumed to weigh three kilograms. The rest of the appliance weight is assumed to be formed from steel (see table 5.56).

<i>Materials</i>	<i>Weights (kg)</i>
Insulation, fibreglass	0.0002
Shell 320 oil 8	0.3
Aluminium, virgin	2
Steel Virgin	6
plastic - general	1.5
Cotton, Fabric	0.0005
Glass, toughened	3
<i>Table 5.56: Portable kerosene heater material quantities.</i>	

5.9.6 LPG heater

A report was published by the New Zealand Institute of Economic Research (NZIER) titled “*Review of Unflued Cabinet Heaters*” (Clough, 2010). NZIER is a company that uses research and analysis to provide specialist advice to clients such as the New Zealand Ministry of Business, Innovation and Employment. The study investigated the environmental risks of unflued LPG cabinet heaters such as poor indoor air quality and linked this information to a review of their usage in New Zealand households. Clough (2010) identified that LPG heaters have a typical life span of four years. A manufacturer of LPG cabinet heaters estimated a weight of 19.9 pounds, which equals approximately nine kilograms.

The materials that form the LPG heater are assumed based on the parts list and assembly detail in an outdoor LPG heater manual (Masport, 2016), and the materials used to form an LPG BBQ. The rubber hose connecting the gas bottle to the heater is assumed to be the same size as the rubber hose on an LPG barbeque. The amount of fixing screws is assumed to be the same as the tumble dryer based on the complexity of the burner construction and the size of the appliance.

The rest of the material quantities are based on a total weight of nine kilograms identified above. The element mesh is assumed to be constructed from copper and weigh 0.5 kilograms. The wheels are assumed to be formed from plastic and weigh one kilogram. An assumption is made that while most of the heater is formed from stainless steel; a steel frame is required to keep the steel in shape. The quantity of steel is assumed to weigh 1.5 kilograms for the frame and the steel grate over the burner. The majority of leftover material quantity is assumed to be stainless

steel, forming the body and weighing four kilograms. The final material quantities are presented in table 5.57.

<i>Materials</i>	<i>Weights (kg)</i>
Stainless steel	4
Rubber	0.5
Steel Virgin	1.5
Nylon (Polyamide) 6 Polymer	1.5
copper virgin	0.5
Metal (Fixing screws)	0.1
<i>Table 5.57: LPG heater material quantities.</i>	

5.9.7 Dehumidifier (with heater)

A supplier of dehumidifiers identified that the appliance has a weight of approximately twenty kilograms (The Home Depot, 2016). “Explain That Stuff” identified that a dehumidifier is similar in functionality and construction to a refrigerator (Explain That Stuff, 2008b). The refrigerator materials are scrutinised in detail for any similarities to the dehumidifier. Explain That Stuff identified the following components that form a dehumidifier:

- Refrigeration system
- Coolant
- Electric fan
- Heating element
- Collection tray
- Plastic float

The coolant and refrigeration system in the dehumidifier is assumed to be twenty-five per cent of a similar system in a refrigerator. Explain That Stuff identified that a heating element is formed from nickel and chromium (Explain That Stuff, 2009). The heating element is assumed to be formed from equal parts of chromium and nickel, and weigh 0.5 kilograms. The amount of aluminium in a dehumidifier is assumed to weigh five kilograms. Plastic is assumed to form the rest of the total weight of the dehumidifier, weighing thirteen kilograms. The final material quantities of a dehumidifier are depicted in table 5.58.

<i>Materials</i>	<i>Weights (kg)</i>
PVC	0.012
Copper (Wiring)	0.164
Aluminium, virgin	5
Metal (Fixing screws)	0.006
ABS	0.2
PVC General	0.314

plastic - general	13
Mastic Sealant	0.388
Shell 320 oil 8	0.034
Refrigerant fluid 8	0.026
Nickel 8	0.5
Chromium	0.5
<i>Table 5.58: Dehumidifier material quantities.</i>	

5.10 Lighting

The following lamps were identified:

- Incandescent
- Halogen
- Compact Fluorescent
- LED
- Heat Lamp

Goodyer (2012) identified that the incandescent and CFL lamps have a lifetime of seven hundred and fifty hours and ten thousand hours respectively. Assuming the lamp runs for approximately six hours per day, every day of the year, the life span of the incandescent lamp is four months, while the CFL lamp life span is approximately four years (Goodyer, 2012). A New Zealand supplier of lamps identified that a halogen lamp has a life span of one thousand five hundred hours, which equates to approximately eight months (Lightbulb Man, undated). A UK study titled “*The Ampere Strikes Back*” explored the idea that appliances are now using more electricity, and are counteracting effort towards slowing climate change through better building regulations. The study identified the following life cycle inventories of the types of lamps identified in the HEEP study (Goodyer, 2012).

<i>Materials</i>	<i>Weights (kg)</i>
Cast Aluminium - Virgin	0.00115
argon	0.00018
Cement, average NZ	0.00145
copper virgin	3.75E-05
Glass - float	0.02054
Nickel	0.00008
Tin	0.00015
Titanium virgin	0.00001
<i>Table 5.59: Incandescent lamp fixed and portable LCI (Goodyer, 2012).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium - Virgin	0.00117
argon	0.00004
Cement, average NZ	0.00145

copper virgin	0.00008
Glass - float	0.02054
Nickel	0.000084
Tin	0.00015
Steel Virgin	0.0002
Zinc Virgin	0.00004
<i>Table 5.60: Halogen lamp fixed and portable LCI (Goodyer, 2012).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
Glass - float	0.01779
Iron	0.0005
Aluminium, virgin	1.33E-05
cement - General	0.00284
plastic - general	0.00993
Silicon	0.01224
Mercury	2.5E-06
argon	0.00031
<i>Table 5.61: Compact fluorescent lamp fixed and portable LCI (Goodyer 2012).</i>	

Yamada and Stober identified that households are now beginning to switch to LED lamps (Yamada and Stober, 2015, p. 10). While no household specifically identified owning an LED lamp in the HEEP study, a tear down study of this appliance is undertaken as these lamps are gradually becoming more cost effective and efficient (Yamada and Stober, 2015, p. 14). It is important to gain an understanding of such a rapidly evolving technology as this will affect the amount of operational energy a household uses and is a consideration for future analysis. This is discussed at the end of this thesis in the *implications and further research* section.

A heat lamp is assumed to be constructed from similar material quantities as an incandescent light bulb. The life span of a heat lamp is assumed to be four months, the same as the life span of an incandescent lamp. Osram is the leading manufacture of lamps in the United States. The technical information sheet of heat lamps outlined that there is a quantity of quartz powder in the construction of a heat lamp (Osram, 2010, p. 5). The weight of the quartz powder is assumed to be 0.001 grams, like the amount of titanium in an incandescent lamp. Table 5.62 depicts the final material quantities used in the analysis.

<i>Materials</i>	<i>Weights (kg)</i>
Aluminium - Virgin	0.00115
argon	0.0002
Cement, average NZ	0.00145
copper virgin	0.0000375
Glass - float	0.02054
Nickel	0.000084
Tin	0.00015
Titanium virgin	0.00001
Quartz powder	0.00001
<i>Table 5.62: Heat lamp material quantities.</i>	

5.11 Garage and garden

5.11.1 Petrol and electric lawn mower

Xing Lan and Yu Liu undertook a study titled “*Life Cycle Assessment of Lawnmowers*” between the years 2009 and 2010. A life cycle assessment was used to evaluate the environmental impact of a petrol-powered lawnmower and an electric lawnmower. A manufacturer and the Centre for Environmental Assessment and Material Systems in Sweden (CPM LCA database) were the main two sources for data collection.

The highest impact phase proved to be manufacturing, highlighting a need for life cycle thinking (LCT) in the design chain. The study included an inventory analysis as part of the life cycle assessment, identifying the life span of a lawn mower as two years. The LCI of a gas (petrol) lawnmower and an electric lawnmower is identified in table 5.63 and 5.64 (Lan and Liu, 2010).

<i>Materials</i>	<i>Weights (kg)</i>
Steel Virgin	21.2706
Manganese	0.025
Silicon	0.123
Chromium	0.005
Vanadium	0.0003
Titanium virgin	0.0001
Aluminium, virgin	7.332
Aluminium, recycled	0.3
Copper virgin	0.1538
Zinc virgin	0.0216
Steel wire, galvanised 6	1.222
High Density Polyethylene (HDPE) Resin	4.225
ABS	0.545
PVC General	0.159
Plastic	1.3002
Rubber	0.0402
Iron	1.6412
Shell 320 oil 8	0.035
Lead - general	0.75
<i>Table 5.63: Gas lawnmower LCI (Lan and Liu, 2010 pp. 9-15).</i>	

<i>Materials</i>	<i>Weights (kg)</i>
ABS	3.08
Aluminium, virgin	0.072
High Impact Polystyrene	3.252
copper virgin	0.512
High Density Polyethylene (HDPE) Resin	0.137
Iron	0.013
Nickel 8	0.027

Shell 320 oil 8	0.323
Nylon (Polyamide) 6 Polymer	0.029
Nylon (polyamide) 6,6 Polymer	0.417
General Polyethylene	0.002
plastic - general	0.155
Polypropylene, Injection Moulding	0.002
General Purpose Polystyrene	1.69
Steel Virgin	2.563
<i>Table 5.64: Electric lawnmower LCI (Lan and Liu, 2010 pp. 32-35).</i>	

5.11.2 Petrol weed eater

The material quantities of a weed eater are established using figures from a seven-year tear down study of common household appliances. This study, conducted at Carnegie Mellon University, disassembled nine to thirteen appliances twice a year, between the years 2007 and 2014, and is therefore an amalgam of a series of smaller papers completed every year. (Carnegie Mellon University, 2014). The weed eater tear down was conducted in 2008 by Anderson et al. (2008). Table 5.65 identifies these figures that are considered the actual material quantities for a weed eater (Andersen et al., 2008).

<i>Materials</i>	<i>Weights (kg)</i>
plastic - general	2.6012
Nylon (Polyamide) 6 Polymer	0.0168
Shell 320 oil 8	0.323
Metal (Fixing screws)	0.0056
Steel - general	2.6012
Aluminium - General	0.0224
<i>Table 5.65: Gas weed eater LCI (Andersen et al., 2008).</i>	

5.11.3 Electric weed eater

A replacement parts website lists all of the parts in the construction of an electric weed eater (Replacement Parts, 2016). Figure 5.17 identifies that the main difference between a gas and electric weed eater is the electrical cord (item 7).

Figure 5.17: Weed eater parts diagram (Replacement Parts, 2016).

The following parts are identified:

1. The handle (plastic)	2. Screws
3. Cord retainer (plastic)	4. On/off switch
5. Trigger (plastic)	6. Tube assembly
7. Electrical cord	8. Housing set (plastic)
9. Assist handle (plastic)	10. Bolt
11. Blade bracket assembly (steel)	12. Motor
13. Wingnut	14. Cover (plastic)
15. Spool and line (plastic and nylon)	16. Cam (plastic)
17. Screw	18. Washer
19. Nut	20. Arm spring (plastic)
21. Spring	22. Line shield (plastic)
23. Housing assembly (plastic)	24. Screw

The material quantities are assumed based on the LCI data obtained for the gas weed eater. Oil is deleted and an electrical cord is added to form the material quantities for an electric weed eater (see table 5.66).

<i>Materials</i>	<i>Weights (kg)</i>
plastic - general	2.6012
Nylon (Polyamide) 6 Polymer	0.0168
PVC	0.012
Copper wiring	0.082
Metal (Fixing screws)	0.0056
Steel - general	2.6012
Aluminium - General	0.0224
<i>Table 5.66: Electric weed eater material quantities.</i>	

5.11.4 Electrical power tools

A retailer of electrical power tools identified a typical warranty of one year (Bunnings Warehouse, undated.a). A drill is assumed to be one of the most common electrical power tools in a household. The drill was part of a seven-year study which disassembled several household appliances each year. A list of parts was obtained and the materials and weights are assumed based on the images in the study (Huo et al., 2007). The following parts and materials are identified:

- Battery (lithium)
- Support Handle (nylon)
- Fixing Screws
- Casing (PVC injected moulding)
- Plastic (various)
- Motor
- Heat sink (steel/iron)
- Battery terminal (iron)
- Chuck assembly (steel)

The weight of an electric drill was identified to be approximately 2.26 kilograms (Berendsohn, 2015). The food processor is the most similar appliance in a household to a power tool, so it is scrutinised for possible similarities, with copper and fixing screws assumed to be the same quantity as that used in a food processor. The LCI of the motor is again based on Electrical Engineering specifications (2011). Iron is assumed to make up four per cent of the total weight, while aluminium is assumed to make up two per cent being half that relative to iron. The rest of the major material quantities are assumed based on the leftover weight (plastic, rubber, steel, lithium, PVC injected moulding and nylon) (see table 5.67).

<i>Materials</i>	<i>Weights (kg)</i>
copper virgin	0.028
plastic - general	0.2
Rubber	0.01
Steel Virgin	1
Iron	0.00904
Aluminium, virgin	0.00452
Metal (Fixing screws)	0.006
Lithium	0.05
PVC Injection Moulding	0.904
Nylon (Polyamide) 6 Polymer	0.006
<i>Table 5.67: Electrical power tool material quantities.</i>	

5.12 General assumptions

The LCI iron (see section 5.7.1) scrutinised in detail, all of the components in an iron. This LCI included that the material quantities in an electrical cord. Formed from a component of PVC and a component of copper wiring, this relatively simple LCI data set is applied to the following appliances. These are all assumed to have a similar length of electrical cord as the iron:

- Kettle
- Bread maker
- Waste master
- Sewing machine
- Cupboard heater
- Stereo
- Heated fish tank
- Tumble dryer
- Cabinet dryer
- Rice cooker
- Electric barbeque
- Single electric blanket
- All heaters

These appliances are assumed to have the same quantities of PVC and copper wiring as the iron, that being six grams and eighty-two grams respectively. The following appliances are assumed to have an electrical cord twice the length of one on an iron:

- Range hood
- Double electric blanket
- Dehumidifier

The quantity of PVC and copper wiring are assumed as twelve grams and one hundred and sixty-four grams for each appliance respectively.

5.13 Summary

This chapter presents the LCI figures established for all household appliances identified in each surveyed case study. The first part of this chapter identifies key sources used for a larger number of appliances before going into detailed lists sourced from one-off sources. The second part of this chapter identifies the appliance categories and how these are decided upon based on the definition of appliances established in chapter four. These appliance categories are:

1. General, small portable appliances
2. Entertainment appliances
3. Washing and drying appliances
4. Kitchen and cooking appliances
5. Space heating appliances
6. Lighting
7. Garage and garden

All appliance LCI data sets are presented in these categories throughout this chapter. The rest of the chapter summarizes how LCI data sets are established for each appliance and all assumptions made in the formation of all data sets.

5.14 The next step: Chapter six

A total Life Cycle Assessment (LCA) considers both the embodied energy and operational energy. Chapter six identifies the sensitivity analysis carried out to determine appropriate wattage and energy consumption figures for the operational energy for each appliance. A sensitivity analysis is conducted for many different appliance examples of each appliance type to determine the most appropriate and representative wattages and usage data to be used in the final analysis for the impact assessment.

Chapter Six

Appliance Data Studies

One hundred and fifty years ago, society dictated that we tame and conquer the Earth, that we bend it to our will, and so we proceeded to spend decades building, moulding and shaping it into something that suited our needs. The industrialization of society led to a cradle-to-grave model of material flows. We extracted what we needed from our environment, made it into products, and used them and then discarded them.

- Professor Braungart (Crocker and Lehmann, 2013, xxii).

6.1 Operational energy

In *Motivating change; Sustainable design and behaviour in the built environment*, Professor Braungart depicts a rather grim outlook of the role society has played in the shaping of our environment. However, Braungart also discusses the need to understand resulting material flows and use of products to possibly determine how behaviour can change this bleak outcome. Having established a series of LCI figures and material flows in chapter five, this chapter focuses on the operational energy of all of the appliances explored in this thesis to better understand the use of products. Here, all the assumptions and measures taken of the wattage and usage figures are established. These are based on an amalgam of HEEP data collected and a series of comparative studies. The data collected during the HEEP study established the usage

for many appliances, but not all. In many cases, this data identifies days of use or number of times an appliance is used without any specific details about how long each appliance is operated. In order to ascertain the total hours of operation for all appliances and a representative wattage figure for each appliance type, this chapter conducts a series of comparative studies or a comparative matrix for all appliances. In the following sections, the wattage and usage figures used for the LCA calculations are discussed for each appliance.

6.2 Wattage and usage

Since wattage and usage figures vary across many different sources, a comparative study is undertaken to establish the most reliable and appropriate figures to use in the LCA. The usage and energy data are obtained using the method of aggregated data by which many units are looked at to establish representative figures. New Zealand, United Kingdom and American sources list many common household appliances and their corresponding wattages and usages. The credibility and relevance of these sources for this study are discussed in detail. Where information is not available, assumptions based on common-sense are applied and discussed. In this section, the following nine sources are briefly discussed:

1. *U.S. Department of Energy (2017).*
2. *Wholesale Solar (2017).*
3. *Daft Logic (2017a).*
4. *ABS Alaskan (2008).*
5. *Alterenergy (Undated).*
6. *Frequency Cast U.K (2016)*
7. *Energy Use Calculator (2017a)*
8. *The Government of Delaware (Undated).*
9. *Warren Recc (2016a)*

These nine sources are used to establish most (not all) of the appliance wattage and usage figures. These are introduced here to avoid redundant repetition when specific appliances are discussed in this chapter. Other sources used for the small number of appliances not found in these sources are discussed individually with each appliance they are used for.

“Energy Saver is the U.S. Department of Energy's (DOE) consumer resource on saving energy and using renewable energy technologies at home” (U.S Department of Energy, undated.a).

This source is used to calculate the energy use of fifty-five appliances. This source identifies figures of wattage, utility rate, hours used per day, and days used per year to calculate a total cost per year. They also identify the important point that refrigeration appliances operate at around a third of their maximum wattage due to their on/off cycle (U.S Department of Energy, undated.b).

Wholesale Solar (2017) lists eighty-one common household appliances and their corresponding wattages. The study identifies that some appliances, such as televisions and television decoders, consume power even when on standby. This study also discusses the operation of refrigerators, suggesting that refrigerators do not operate at the maximum wattage continuously (Wholesale Solar, 2017). These two usage implications are considered in the calculation of operational energy below.

“Daft Logic is a collection of resources, tools and information” (Daft Logic, 2017a). One of the articles in this open source repository titled *“List of the Power Consumption of Typical Household Appliances”*, lists a minimum, maximum and standby wattage figure for forty-three common household appliances (Daft Logic, 2017b).

ABS Alaskan (2008) is a company that sells solar energy equipment, and reports on the wattage of household appliances such as dishwashers and ovens. They have produced a power consumption table which identifies the wattage of eighty-four household appliances. Here, either an average wattage or a range of wattages for each appliance are listed. This study also compares the wattage output of different lighting types (ABS Alaskan, 2008). The ABS Alaskan study provides very detailed figures for lighting that is used later in the implications chapter to discuss possible use figures in the future.

Alterenergy (undated) provides information about alternative energy and on/off grid applications. This open source repository lists wattage figures for thirty-four common household appliances. This is a New Zealand specific study that uses figures for New Zealand electricity and aligns with the HEEP data gathered from New Zealand households (Alterenergy, undated.)

Frequency Cast U.K (2016) compiles a list of common household appliances and identifies the wattage, cost per hour, and the daily usage for each. Frequency Cast uses a plug-in mains power and energy monitor to measure the actual wattage of common household appliances. The meter

is plugged directly into the electrical socket between the appliance and the direct power (see figure 6.1). These devices are typically used to measure voltage, amps and wattage, and are a reliable source for establishing appliance wattage figures (Frequency Cast, 2016).

Figure 6.1: Plug-In Mains Power and Energy Monitor used to measure wattage (Frequency Cast, 2016).

Energy Use Calculator (2017a) provides tools for homeowners to calculate their current energy usage and is used to help reduce energy costs through advice and articles (Energy Use Calculator, 2017a). This US open source repository lists online energy calculators for several common household appliances. The calculator displays an input for the hours used per day (usage), the wattage, and the price per kWh to calculate the total cost per year (see figure 6.2).

A screenshot of a web-based energy calculator. On the left, a yellow box contains the following labels: 'Cost Per Hour:', 'Cost Per Day:', 'Cost Per Month:', 'Cost Per Year:', and 'kWh Per Day:'. On the right, there are input fields for 'Hours Used Per Day:' (with the value 0.25), 'Power Use (Watts):' (with the value 1100), and 'Price (kWh):' (with the value 0.10). Below these fields are two buttons: 'Calculate' and 'Reset'.

Figure 6.2: Example of the Energy Use Calculator for an iron. All figures are automatically set (Energy Use Calculator, 2016a).

The Government of Delaware (undated) has an energy consumption list of common household appliances. This database lists the wattage, usage and cost per year of fifty-six household appliances (Government of Delaware, undated.). The source groups the appliances in the following categories:

1. Large Appliances
2. Comfort Appliances
3. Small Appliances
4. Miscellaneous
5. Home Care Appliances
6. Pool and Pumps
7. Electronics

Warren Recc (2016a) is an electricity provider that provide electricity to eight counties in the United States. The Warren Recc database provides information about energy use, patterns and trends (Warren Recc, 2016a). The open source repository lists the wattage, average usage and cost per month of many common household appliances (Warren Recc, 2016ab). The appliance list covers the following categories:

- Comfort and health
- Food preparation and preservation
- Laundry
- Home entertainment and recreation
- Lighting
- Farm equipment

6.3 Appliance categories

As outlined in chapter five, section 5.3, categories are created to logically present household appliances based on their use. The table below identifies the appliance categories established for the LCA process. This is the same order in which the wattages and use of appliances are discussed in this chapter. The gas appliances are discussed collectively after the heating appliances.

Appliance category	Personally related	Spatially related
General, small portable appliances	✓	
Entertainment appliances	✓	
Washing and drying appliances	✓	✓
Kitchen and cooking appliances	✓	✓
Space heating appliances		✓
Lighting	✓	✓
Garage and garden	✓	✓

6.4 Appliances with wattage that varies across usage

Three sources identified that some appliances use a varying amount of wattage over the total usage. The U.S Department of Energy identifies that utilising the average wattage of a refrigerator, combination fridge-freezer or a deep freezer will create inaccurate calculations of operational energy because the appliance's on-off cycle is controlled by a thermostat. The Department established that using one-third of the total wattage in the calculation of operational energy provides more accurate results for refrigeration appliances (U.S Department of Energy, undated.b). Emmons et al. (1998) identify the wattage of sixteen household appliances. They establish that several appliances, such as video players, stereos and televisions, do not draw the full power continuously. Some appliances have a change in wattage during different functions, i.e. change in volume, and that some appliances draw power even when on standby mode (Emmons et al., 1998). A paper titled “*Standby and Baseload in New Zealand Houses: A nationwide statistically representative study*” (Camilleri et al., 2006) presents the results of the electrical power monitoring that is part of the HEEP project. Two to three appliances were monitored each month over 12 months in 98 of the houses identified in the study. Each appliance was measured for a period between 10 and 15 minutes to estimate the standby power of each appliance and eventually the baseload of each house (Camilleri et al., 2001, p. 3).

This established the standby wattage of every electrical appliance identified by households in the HEEP study (Camilleri., 2006, p. 71-72). This data is considered in the calculation of operational energy. If no consideration of standby power is made for the appliance then the appliance is assumed to either be switched off at the wall when not in use or have no standby power. These points are introduced here to avoid redundant repetition when specific appliances are discussed.

6.5 General. Small portable appliance

6.5.1 Vacuum cleaner

The following wattages are identified for a vacuum cleaner:

Wattage	500	200-700	100-700	1,100	542	1,400	300-1,000
Source	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2017b)	(Government of Delaware, undated.)

Table 6.1: Estimated wattages for a vacuum cleaner.

The wattage for a vacuum cleaner is estimated between 100 and 1,400 Watts. The average taken between the highest and lowest figures is 750 Watts. Since two sources identify similar estimates for wattage, 700 Watts is selected to represent the wattage of a vacuum cleaner. Two sources estimate the usage of a vacuum cleaner:

<i>Usage</i>	70 mins/week	15-60 mins/week
<i>Source</i>	(Energy Use Calculator, 2017b)	(Government of Delaware, undated.)

Table 6.2: Estimated usage figures of a vacuum cleaner.

The range of usages for a vacuum cleaner is estimated between fifteen and seventy minutes a week. An average between the highest and lowest estimate of forty minutes per week is utilised in the research.

6.5.2 Sewing Machine

ABS Alaskan (2008) estimate the wattage of a sewing machine at 100 Watts (ABS Alaskan, 2008). No source was obtainable for sewing machine usage so a common-sense approach is applied. A sewing machine is assumed to run for seven hours per year like a lawnmower, weed eater and electric power tools discussed in the *garage and garden appliances* section. This assumption is made because these specific appliances are used rarely throughout the year, and are used for very specific purposes.

6.5.3 Cupboard heater

Dampchaser is a New Zealand company that manufacture cupboard heaters. Not only are they a credible source of wattage information because they manufacture and sell cupboard heaters, but they are also New Zealand based so the data aligns with the New Zealand HEEP study analysed in this research. Dampchaser identifies a wattage figure of 17 Watts for a cupboard heater (Dampchaser, 2008). A thermostat controls the temperature of the cupboard heater so 6 Watts, one-third of the overall wattage is used in the LCA (U.S Department of Energy, undated.b). There is no obtainable source to identify the usage of a cupboard heater so a common-sense approach is applied. A cupboard heater is assumed to run for twenty-four hours a day, every day of the year. This estimate is based on the functionality of a cupboard heater in that the purpose is to eliminate dampness in a wardrobe and maintain a dry environment (Dampchaser, 2008).

6.5.4 Heated towel rail

A New Zealand manufacturer of heated towel rails identifies that the appliance wattage can range anywhere between 35 and 2,400 Watts (Skope, 2011). As it is unclear which size of heated towel rails are used in New Zealand households, the most common figure of 95 Watts is chosen for the analysis. This appliance has a thermostat that controls the overall temperature of the appliance so the heated towel rail does not operate at 95 Watts all the time (U.S Department of Energy, undated.b). An assumption is made that 32 Watts will more reliably represent the operation as one-third of the maximum wattage. A report titled *“Standby and Baseload in New Zealand Houses: A nationwide statistically representative study”* investigates appliance standby and baseload energy consumption in New Zealand. They identify the standby wattage of 68 appliances that are identified in the HEEP study. They also identify that approximately half of households leave a heated towel rail on continuously (Camilleri et al., 2006, p. 68). An assumption is made that the average usage of a heated towel rail is twelve hours a day, every day of the year.

6.5.5 Extractor fan

Alterenergy estimates the wattage of an extractor fan at 40 Watts, while Warren Recc estimates the usage to be two hours per day (Alterenergy, undated; Warren Recc, 2016ab). An extractor fan is assumed to be installed in the bathroom of a household. The usage figure of two hours, when compared to the usage figure of a bathroom heater (one hour) makes sense. The fan is likely switched on at the same time as the bathroom heater but then switched off much later when the humidity of the room has decreased.

6.5.6 Heated fish tank

A New Zealand supplier of aquarium heaters identifies that the wattage ranges anywhere between 25 and 300 Watts (Pet, 2013). The average between these two figures is approximately 160 Watts. A thermostat controls the temperature of the heater so a more appropriate figure of 50 Watts is selected as one-third of the overall usage (U.S Department of Energy, undated.b). The Government of Delaware estimates the usage of a heated fish tank to be twenty-four hours a day, every day of the year (Government of Delaware, undated). This usage figure is appropriate because heated fish tanks are required to be running constantly to support the life of tropical fish.

6.6 Entertainment appliances

6.6.1 Televisions

The usage of this appliance is presented first to consider how long the appliance operates on standby. An assumption is made that there is no difference in usage between television types identified in the study. The following usages are established for televisions:

<i>Usage</i>	4 hours/day	5 hours/day	35 hours/week	4 hours/day
<i>Source</i>	(Frequency Cast, 2016)	(Energy Use Calculator, 2017c)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.3: Estimated usage figures of a television.

The Warren Recc estimate is converted to five hours per day, so it is comparable with the other sources. A range of usages for a television is estimated between four and five hours a day. Since the sources are reasonably close in terms of estimated usage, an average of 4.5 hours per day, every day of the year is used in this research. An assumption is made that the television operates on standby power for 19.5 hours a day, i.e. the rest of the time. Camilleri et al. (2006) identify the standby wattage of a television as 5.2 Watts (Camilleri et al., 2006, p. 71). This equates to around 100 extra Watts per day. For the calculation of total operational energy to make sense from the product of Watts and hours, this is an additional 22 Watts added to the wattage when the appliance is used for 4.5 hours. The following wattages are identified for televisions where it was clear what type of television was being identified:

Plasma	339	300	320	339
<i>Source</i>	(Wholesale Solar, 2017)	(U.S Department of Energy, undated.b)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)
LCD	213	150	115	213
<i>Source</i>	(Wholesale Solar, 2017)	(U.S Department of Energy, undated.b)	(Frequency Cast, 2016)	(Government of Delaware, undated.)
LED	40-100			
<i>Source</i>	(Daft Logic, 2017b)			
Other	Analog	CRT	DPL	HDTV
<i>Sourced from; U.S Department of Energy. (undated.b).</i>	86 watts (<40 inches) 156 watts (>40 inches)	60	175	150 watts (<40 inches) 234 watts (>40 inches)

Table 6.4: Estimated wattages for televisions.

The wattage for a plasma television is estimated between 300 and 339 Watts. The lower figure of 300 Watts more reliably represents the change in wattage during operation (Emmons et al., 1998). The range of wattages for an LCD television is estimated between 115 and 230 Watts. The average between these two figures is 170 Watts. Considering the appliance operation when on standby, the figures of 320 and 200 Watts are selected for plasma and LCD respectively.

The wattage for an LED television is estimated between 40 and 100 Watts. This equates to an average of 70 Watts. 80 Watts is chosen for the analysis to more reliably represent the entire usage. An assumption is made that the standby wattage for an LED television is much lower than the other television types. Since only one wattage figure is identified for the other types of televisions, 22 standby Watts are added to these estimates for use in the calculation of operational energy. These are presented in table 6.48.

6.6.2 Computer

Table 6.5 presents the varying usage of a computer:

<i>Usage</i>	8 hours/day	6 hours/day	4 hours/day	2 hours/day
<i>Source</i>	(Frequency Cast, 2016)	(Energy Use Calculator, 2017d)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.5: Estimated usage figures of a computer.

The usage of a computer is estimated between two and eight hours a day. Since the sources are reasonably close in terms of estimated usage, an average between the highest and lowest estimate of five hours per day, every day of the year is used in the research. An assumption is made that the computer operates on standby power for nineteen hours per day i.e. the rest of the time. Camilleri et al. (2006) identify the standby wattage of a computer and monitor as 9.7 Watts, this equates to 184.3 additional Watts per day (Camilleri et al., 2006, p. 71). For the calculation of operational energy to makes sense, this is an additional 37 Watts over five hours of usage. The following wattages are identified for a computer:

<i>Wattage</i>	40-1,000	100-450	80-150	200	100
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(Energy Use Calculator, 2017d)
<i>Wattage</i>	75	90	500	170	
<i>Source</i>	(U.S Department of Energy, undated.b)	(Frequency Cast, 2016)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)	

Table 6.6: Estimated wattages for a computer.

The range of wattages for a computer is estimated between 40 and 1,000 Watts. 1,000 Watts is the outlier in this data and an assumption is made that this refers to a high-end gaming computer. 500 Watts more reliably represents the maximum wattage of an average household computer. The average between 40 and 500 Watts is 270 Watts. A lower figure of 260 Watts more reliably represents the change in power during operation (Emmons et al., 1998). 300 Watts is chosen to represent both the change in usage during operation and the standby power for this appliance.

6.6.3 Video game player

An assumption is made that a video game player has the same usage as a computer, that being five hours of usage and nineteen hours of standby power per day. Camilleri et al. (2006) identify the standby wattage of this appliance as 5.2 Watts, this equates to around 100 additional Watts per day. For the operational energy calculation to make sense, this is an additional 20 Watts over five hours of usage. The following wattages are identified for a video game player:

<i>Wattage</i>	195	36	90	195
<i>Source</i>	(Wholesale Solar, 2017)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2017e)	(Government of Delaware, undated.)

Table 6.7: Estimated wattages for a video game player.

The wattage for a video game player is estimated between 36 and 195 Watts. An average taken between the highest and lowest figures is 115 Watts. 100 Watts more reliably represents the change in power during operation. 120 Watts is chosen to represent total operation when considering standby mode (Emmons et al., 1998; Camilleri et al., 2006, p. 71).

6.6.4 Video player

The usage for a video player is presented before the wattage to understand the amount of standby power this appliance has:

<i>Usage</i>	4 hours/day	4 hours/day	24 hours/day	2 hours/day
<i>Source</i>	(Frequency Cast, 2016)	(Warren Recc, 2016ab)	(Energy Use Calculator, 2017f)	(Government of Delaware, undated.)

Table 6.8: Estimated usage figures of a video player.

Frequency Cast and Warren Recc identify the usage of a video player as four hours a day, every day of the year. An assumption is made that the video player is on standby for twenty hours a day i.e. the rest of the time. Camilleri et al. (2006) identify the standby wattage of a video player as 9.4 Watts, this equates to 188 additional Watts per day (Camilleri et al., 2006, p. 71).

For the calculation of operational energy to make sense, this is an additional 47 Watts over the four hours of usage. A video player was identified to have a wattage that ranged between 17 and 25 Watts (Emmons et al., 1998). A video player, like a television, uses a different amount of wattage depending on the function. 17 Watts is used to represent a more reliable wattage with an additional 47 Watts of standby operation (64 Watts total).

6.6.5 Stereo

The Government of Delaware estimates the usage of a stereo to be one hour a day, every day of the year (Government of Delaware, undated). An assumption is made that this appliance is on standby for twenty-three hours a day i.e. the rest of the time. Camilleri et al. (2006) identify the standby wattage of this appliance as 7.1 Watts, this equates to 163.3 Watts of additional operation (Camilleri et al., 2006, p. 71). The following wattages are identified for a stereo:

<i>Wattage</i>	60	10-35	85	33	60
<i>Source</i>	(Wholesale Solar, 2017)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Government of Delaware, undated.)

Table 6.9: Estimated wattages for a stereo.

The range of wattages for a stereo is estimated between 10 and 85 Watts. The average wattage taken between the highest and lowest figure is 47.5 Watts. 40 Watts is used to more reliably represent a stereo's wattage during operation, while 200 Watts represents the total operation when considering standby mode (Emmons et al, 1998).

6.6.6 Radio cassette player

An assumption is made that the usage of a radio cassette player is one hour of actual usage and twenty-three hours of standby usage per day, the same as the stereo. Camilleri et al. (2006) identify the standby power of this appliance at 1.7 Watts. This equates to 39.1 Watts of additional wattage per day (Camilleri et al., 2006, p. 71).

A manufacturer, Sony, establishes the wattage of a radio cassette player as 12 Watts (Sony, 2017b). 45 Watts is chosen to more reliably represent the total operation of a radio cassette player (Emmons et al. 1998).

6.6.7 Television decoder

Three sources estimate the wattage of a television decoder:

<i>Wattage</i>	20	18.2-24	33
<i>Source</i>	(U.S Department of Energy, undated.b)	(Frequency Cast, 2016)	(Government of Delaware, undated.)

Table 6.10: Estimated wattages for a television decoder.

The wattages for a television decoder range from 18.2 to 33 Watts. An average taken between these figures is 25.6 Watts. The U.S Department of Energy identifies the wattage of a television decoder as 20 Watts. The figure identified by a government entity is chosen to represent a more reliable wattage. This lower figure also more reliably represents the varying wattage of the appliance during use (Emmons et al., 1998). The following usages are identified for a television decoder:

<i>Usage</i>	24 hours/day	2 hours/day
<i>Source</i>	(Frequency Cast, 2016)	(Government of Delaware, undated.)

Table 6.11: Estimated usage figures of a television decoder.

The Government of Delaware identifies a usage figure of two hours a day, every day of the year. While they proved to be a more credible source as a government entity, a common-sense approach is applied. The television decoder is assumed to be left on continuously by a New Zealand household. While the usage figure of two hours a day calls into question the accuracy of the other wattage and usage figures supplied by the Government of Delaware, this figure aims to represent the usage of a television decoder if households switch this appliance off at the wall when not in use. Since this appliance operates twenty-four hours a day there is no consideration of standby energy.

6.7 Washing and drying appliances

6.7.1 Iron

Table 6.12 shows the varying wattage of an iron:

<i>Wattage</i>	1,100	1,000	1,000	1,400	1,100	1,100	1,008
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2016a)	(Warren Recc, 2016ab)

Table 6.12: Estimated wattages for an iron.

The range of wattages for an iron is estimated between 1,000 and 1,400 Watts. The U.S Department of Energy and Wholesale Solar identify the wattage of an iron at 1,100 Watts. This appliance operates with a thermostat so 370 Watts, one-third of the overall wattage, is chosen

for the LCA (U.S Department of Energy, undated.b). Three sources estimate the usage of an iron:

<i>Usage</i>	15 mins/day	2 hours/week	1 hour/week
<i>Source</i>	(Energy Use Calculator, 2016a)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.13: Estimated usage figures of an iron.

The estimate of fifteen minutes per day is converted to 1.75 hours per week so it is comparable with the other two sources. Since the sources are reasonably close in terms of estimated usage, an average between the highest and lowest estimate of 1.5 hours per week is chosen for the usage of an iron.

6.7.2 Dishwasher

A manufacturer, Whirlpool, identify that a dishwasher's cycle time can be anywhere between 1.5 and 4 hours (Whirlpool, 2016). A dishwasher is estimated to run for an average of three hours per day, every day of the year. An assumption is made that the dishwasher has a standby usage of twenty-one hours a day i.e. the rest of the time. The following wattages are identified for a dishwasher:

<i>Wattage</i>	1,200-1,500	1,200-1,500	1,200-1,500	2,000	330	1,800	1,200
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2017g)	(Warren Recc, 2016ab)

Table 6.14: Estimated wattages for a dishwasher.

The wattage of a dishwasher is estimated to range between 330 and 2,000 Watts. The outlier of 330 Watts is assumed to represent the operation of the appliance when it is not heating. One-third of the maximum wattage (388 Watts) more reliably represents total operation (U.S Department of Energy, undated.b). Camilleri et al. (2006) identify the standby wattage of a dishwasher as 1.6 Watts, this equates to 33.6 additional Watts per day or an additional 11.2 Watts over three hours of usage (Camilleri et al., 2006, p. 71). 400 Watts is chosen to more reliably represent the overall operation of this appliance.

6.7.3 Washing machine

The Building Research Association of New Zealand (BRANZ) identifies that a typical New Zealand household has 5.6 loads of washing per week, which equates to nearly one load of

washing per day. This study monitors water use from fifty-one randomly selected homes from February to September 2008 (BRANZ, 2008). BRANZ identify that out of the fifty-one samples, ninety-four per cent own top-loader washing machines. Steen (2016) establishes the run cycle of various washing machines including those made by Bosch, Fisher and Paykel, LG, Miele, Samsung and Simpson. The study identifies the change in average cycle times of a washing machine over a ten-year period (see table 6.15) (Steen, 2016).

<i>Type of washing machine</i>	<i>Cycle time 10 years ago</i>	<i>Cycle time today</i>
Top loader	55 minutes	58 minutes
Front loader	99 minutes	118 minutes
<i>Table 6.15: Run cycle times of washing machines over a ten-year period.</i>		

A top loader washing machine is estimated to run between fifty-five and fifty-eight minutes per cycle. The average usage of a washing machine is 56.5 minutes a day, every day of the year. Camilleri et al. (2006) identify the standby wattage of a washing machine as 3.1 Watts, this equates to 71.3 additional Watts per day (Camilleri et al., 2006, p. 72). Seven out of the nine open source repositories compared in the comparative study identify the wattage of a washing machine:

<i>Wattage</i>	500	500	2,000	250-2,000	255	500	512
<i>Source</i>	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(Frequency Cast, 2016)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2017h)	(Warren Recc, 2016ab)
<i>Table 6.16: Estimated wattages for a washing machine.</i>							

Three sources estimate the wattage of a washing machine at 500 Watts. The highest figure of 2,000 Watts is assumed to apply when the washing machine is washing with hot water. Since there is no way of identifying if New Zealand households wash with hot water and how often, the most common wattage figure of 500 Watts is assumed to be the average wattage of a washing machine. 570 Watts is chosen to represent the operation and standby usage of this appliance.

6.7.4 Tumble dryer

A manufacturer, Maytag, identifies that a tumble dryer has a run cycle of an hour (Maytag Commercial, 2016). An analysis is undertaken to establish the days per week a dryer typically operates in New Zealand. The National Institute of Water and Atmospheric Research (NIWA)

identifies the average hours of sunshine in the main cities of New Zealand (see table 6.17). The historical weather data that forms the averages below are collected over three decades, from 1981 to 2010 (NIWA, 2010).

<i>City</i>	<i>Average hours of sunshine a year</i>
<i>North Island</i>	
Auckland	2,003
Gisborne	2,218
Hamilton	2,020
Kaitaia	2,116
Masterton	1,982
Napier	2,259
New Plymouth	2,197
Palmerston North	1,744
Rotorua	2,128
Taupo	1,951
Tauranga	2,346
Wanganui	2,055
Wellington	2,110
<i>South Island</i>	
Alexandra	2,006
Blenheim	2,475
Christchurch	2,143
Dunedin	1,684
Hokitika	1,894
Invercargill	1,682
Kaikoura	2,137
Lake Tekapo	2,417
Manapouri, Te Anau	1,661
Mt Cook, Hermitage	1,581
Nelson	2,472
Queenstown	1,929
Timaru	1,932
Westport	1,799
Chatham Islands	1,437
Average	2,014
<i>Table 6.17: Average hours of sunlight per year for the main cities in New Zealand. Source: NIWA (2010).</i>	

Sunshine hours in a year across New Zealand average at 2,014 hours out of a possible 4,383 hours of daylight per year (Clima Temps, 2014). It is incorrect to assume that the dryer is running for the 2,369 hours where sunlight is not available.

This analysis identifies that there is approximately forty-six per cent chance of sunlight per year. BRANZ acknowledge above that a New Zealand household has typically 5.6 loads of washing per week, so an assumption is made that a tumble dryer is used once per week to assist with natural drying. The following wattages are identified for a dryer:

<i>Wattage</i>	3,400	1,000-4,000	4,000	1,400	2,790	3,000	4,900
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2017i)	(Warren Recc, 2016ab)
<i>Table 6.18: Estimated wattages for a dryer.</i>							

The range of wattages for a dryer is estimated between 1,000 and 4,900 Watts. The average wattage between these figures is 2,950 Watts. A tumble dryer is controlled by a thermostat so 980 Watts is chosen for the calculation of operational energy (U.S Department of Energy, undated.b). An assumption is made that households switch this appliance off when it is not in use.

6.7.5 Cabinet dryer

A manufacturer of drying cabinets identifies the wattage of the appliance at approximately 1,550 Watts (Peko Drying Cabinets, 2017). One-third of the maximum wattage is 520 Watts. This wattage is chosen to represent the operation of this appliance when controlled by a thermostat (Emmons et al., 1998). A cabinet dryer is estimated to run for one hour a week. This is based on a typical run cycle in a cabinet dryer operational manual (Asko, undated.). Similarly, to a tumble dryer, the cabinet dryer is assumed to be in use once a week to assist with natural drying. An assumption is made that households also switch this appliance off when not in use so standby power is not considered in the LCA of a cabinet dryer.

6.8 Kitchen and cooking appliances

6.8.1 Refrigerator, combination fridge-freezer and deep freezer

Table 6.19 shows the varying wattage for a refrigerator:

<i>Wattage</i>	225	35	180	440
<i>Source</i>	(U.S Department of Energy, undated.b)	(Frequency Cast, 2016)	(Energy Use Calculator, 2016b)	(Warren Recc, 2016ab)
<i>Table 6.19: Estimated wattages for a refrigerator.</i>				

The wattage of a refrigerator is estimated between 35 and 440 Watts. Frequency Cast obtains wattage figures by using a power meter to measure the actual wattage. This explains the low outlying figure of 35 Watts obtained during the appliances' off-cycle. An average wattage of 240 is calculated between the lowest and highest figure. The U.S Department of Energy

suggests taking one-third of a refrigerator's maximum wattage to more reliably represent the 'on/off cycle' operation of this appliance (U.S. Department of Energy, undated.b). A more accurate wattage figure of 80 Watts is an accurate depiction of the overall usage.

<i>Wattage</i>	150-400	60-540
<i>Source</i>	(Daft Logic, 2017b)	(ABS Alaskan, 2008)

Table 6.20: Estimated wattages for a combination fridge-freezer.

The wattages shown in table 6.20 identify the various wattages established for a combination fridge-freezer. The range for these is estimated between 60 and 540 Watts. Taking the average between the lowest and highest figures, that being sourced from ABS Alaskan, is 300 Watts. To account for the appliances 'on/off cycle,' a more reliable estimate of wattage is 100 Watts. This is the figure used in the analysis to calculate operational energy. Four sources identify the wattage of a deep freezer:

<i>Wattage</i>	50-440	200	200	341
<i>Source</i>	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(Energy Use Calculator, 2017j)	(Warren Recc, 2016ab)

Table 6.21: Estimated wattages for a deep freeze.

The wattage of a deep freezer is estimated between 50 and 440 Watts. The average between the highest and lowest figures is 245 Watts. Considering the way the appliance operates, as identified by the U.S. Department of Energy, a more accurate wattage figure is 80 Watts like the refrigerator (U.S. Department of Energy, undated.b). While Camilleri et al. (2006) shows that a refrigerator, combination fridge-freezer and freezer have a high standby wattage, these appliances are identified to never really be on standby but instead in an 'on/off' cycle usage pattern (Camilleri et al., 2006; U.S. Department of Energy, undated.b). The following usages are identified for a refrigerator, combination fridge-freezer and deep freezer:

<i>Usage</i>	24 hours/day	12 hours/day	24 hours/day
<i>Source</i>	(Energy Use Calculator, 2017j)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.22: Estimated usage figures of a refrigerator, combination fridge-freezer and freezer.

Two sources identified a usage of twenty-four hours per day, every day of the year for a refrigerator, combination fridge-freezer and freezer. The function of these appliances is to preserve food, explaining this high usage figure. Warren Recc identifies the usage as twelve hours a day. While this calls into question the reliability of their figures, they refer to U.S. Department of Energy who state that these appliances have an 'on/off' cycle. This usage of

twelve hours attempts to model a more reliable operation of the appliance and strengthens Warren Recc's figures.

6.8.2 Toaster

Seven out of the nine open source repositories compared in the comparative study identify the wattage of a toaster:

<i>Wattage</i>	1,100	800-1,800	800-1,500	1,400	1,100	1,200	1,100
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2016c)	(Government of Delaware undated)

Table 6.23: Estimated wattages for a toaster.

The range of wattages for a toaster is estimated between 800 and 1,800 Watts. The U.S Department of Energy, the Government of Delaware and Wholesale Solar proved to be the most reliable sources as they are either government entities or claim to be using government data. They identify the same figure of 1,400 for the wattage of a toaster. A toaster has a thermostat controlling the temperature of the appliance, so 460 Watts is chosen for this study to represent one-third of the maximum wattage (U.S Department of Energy, undated.b). The usages time of a toast are:

<i>Usage</i>	12 mins/day	30 minutes/week
<i>Source</i>	(Energy Use Calculator, 2016c)	(Government of Delaware, undated.)

Table 6.24: Estimated usage figures of a toaster.

The estimate of twelve minutes per day is converted to eighty-four minutes per week so it is comparable with the other source. An average of one hour per week between these two figures is used in the research. Camilleri et al. (2006) identify the standby wattage of a toaster as 0.1 Watts (Camilleri et al., 2006). This equates to an additional 2.4 Watts per day and is too insignificant to include in the analysis.

6.8.3 Electric jug (kettle)

Table 6.25 shows the estimates of wattage for an electric jug:

<i>Wattage</i>	1,200-3,000	2,400	1,800
<i>Source</i>	(Daft Logic, 2017b)	(Alterenergy, undated.)	(Frequency Cast, 2016)

Table 6.25: Estimated wattages for an electric jug.

The wattage for an electric jug is estimated between 1,200 and 3,000 Watts. Since the wattage varies significantly between the sources, and the average between the sources is similar to Alterenergy's estimate of 2,400 Watts, this figure is chosen for the analysis.

An assumption is made that this appliance operates at the maximum wattage until the thermostat switches it off. One source, Frequency Cast, estimate the usage of a kettle at fifteen minutes per day (Frequency Cast, 2016). An assumption is made that a kettle is in use every day of the year and that this appliance has no standby power.

6.8.4 Coffee maker

Eight of the nine open source repositories analysed in the comparative study identify the wattage of a coffee maker:

<i>Wattage</i>	1,500	800-1,400	800	750	1,000	800	894	600-1,500
<i>Source</i>	(Whole sale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2016d)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.26: Estimated wattages for a coffee maker.

The range of wattages for a coffee maker is estimated between 600 and 1,500 Watts. Most sources above are quoting American figures. American coffee machines typically continue warming the coffee pot, whereas the coffee machines in New Zealand are more instant. A New Zealand supplier of coffee machines identifies that out of 31 models available, 30 models are instant machines (Harvey Norman, 2017b). 750 Watts is a more reliable figure to use in the calculation of operational energy. An assumption is made that this appliance operates at the maximum wattage until it switches off. Three sources identify the usage of a coffee machine:

<i>Usage</i>	20 mins/day	1 hour/day	15-30 mins/day
<i>Source</i>	(Energy Use Calculator, 2016d)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.27: Estimated usage figures of a coffee maker.

The Warren Recc usage estimate is converted to sixty minutes per day, so it is comparable with the other sources. The lower estimate of fifteen minutes per day more appropriately represents the usage of instantaneous coffee machines used in New Zealand.

6.8.5 Food processor and mixer

The following wattages are identified for a food processor:

<i>Wattage</i>	300-400	375	400
<i>Source</i>	(Daft Logic, 2017b)	(Alterenergy, undated.)	(Warren Recc, 2016ab)

Table 6.28: Estimated wattages for a food processor.

The range of wattages for a food processor is estimated between 300 and 400 Watts. A wattage of 375 Watts is selected for a food processor because it relates to the New Zealand data gathered in the HEEP study. Table 6.29 shows the varying usage estimated for a mixer:

<i>Wattage</i>	300	300	400
<i>Source</i>	(Wholesale Solar, 2017)	(ABS Alaskan, 2008)	(Warren Recc, 2016ab)

Table 6.29: Estimated wattages for a mixer.

The wattage of a mixer is identified to be 300 Watts from two different sources and is the figure chosen for this study. Warren Recc estimate the usage of a food processor or mixer to be one hour per week (Warren Recc, 2016ab). An assumption is made that households switch these appliances off when they are not in use so no standby power was considered in the LCA calculations for these appliances.

6.8.6 Bread maker

A New Zealand supplier of bread makers, Briscoes, list four bread makers on their website. They identify the wattage to range from 450 to 650 Watts (Briscoes, 2011a). An average taken between the highest and lowest estimate is 550 Watts. This appliance is controlled by a thermostat so 180 Watts is used in the analysis to calculate the operational energy of a bread maker (U.S Department of Energy, undated.b). A bread maker is assumed to be in used for fifteen hours a month (Byfield, 2009). An assumption is made that households switch off this appliance when it is not in use.

6.8.7 Rice cooker

A study titled “*Energy Conservation in Domestic Rice Cooking*” investigates how different preparation and cooking methods affected the energy output of rice cooking. Two methods of preparation; un-soaked and pre-soaked rice, are cooked using two electronic appliances; a rice cooker and a pressure cooker (Das et al., 2006, p 2). The study identifies that a 450 Watt rice cooker has a thermostat that switches the appliance off when there is no water content (Das et

al., 2006, p. 4). One-third of the maximum wattage (150 Watts) is selected to represent the operation of this appliance when controlled by a thermostat (U.S Department of Energy, undated.b). An assumption is made that this appliance has no standby power because it is switched off when it is not in use.

6.8.8 Crock pot

The following wattages are identified for a crock pot:

<i>Wattage</i>	230	200
<i>Source</i>	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)

Table 6.30: Estimated wattages for a crockpot.

The wattage of a crockpot is estimated similarly by two sources. Since both sources are reasonably close in terms of estimated wattage, the New Zealand figure of 230 Watts is chosen to represent the maximum wattage of this appliance. The crock pot is also controlled by a thermostat so 80 Watts, one-third of the maximum wattage, is used to calculate the operational energy of the crock pot (U.S Department of Energy, undated.b). It is assumed that households switch this appliance off when not in use.

6.8.9 Microwave

Seven of the nine open source repositories compared in the comparative study identify the wattage of a microwave:

<i>Wattage</i>	1,500	600-1,700	600-1,500	750	1,500	1,200	1,500
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(U.S Department of Energy, undated.b)	(Energy Use Calculator, 2016e)	(Government of Delaware, undated.)

Table 6.31: Estimated wattages for a microwave.

The wattage of a microwave ranges between 600 and 1,700 Watts. The New Zealand figure of 750 Watts is selected to represent the maximum wattage of this appliance. A microwave is an appliance that uses standby power to display a digital clock. Camilleri et al. (2006) identify the standby wattage of a microwave as 3.6 Watts. A microwave is estimated to run for thirty minutes a week to assist with day to day cooking, equating to around four minutes a day (Energy Use Calculator, 2016e; Warren Recc, 2016ab). The appliance uses the lower standby wattage for 23.94 hours a day. This equates to an additional 86 Watts of standby power each day or 1,400 Watts for thirty minutes of usage per week totalling 2,150 Watts for total operation.

6.8.10 Waste master

Four sources estimate the wattage of a waste master:

<i>Wattage</i>	450	450	400	750
<i>Source</i>	(Wholesale Solar, 2017)	(ABS Alaskan, 2008)	(U.S Department of Energy, undated.b)	(Government of Delaware, undated.)

Table 6.32: Estimated wattages for a waste master.

The wattage for a waste master is estimated between 400 and 750 Watts. Two sources identify the same figure for wattage, and since the range of the four sources is low, 450 Watts was chosen as the figure used in this analysis. One open source repository, the Government of Delaware, estimate the usage of a waste master to be fifteen minutes per day, every day of the year (Government of Delaware, undated). Camilleri et al. (2006) identify that the waste master has no standby wattage (Camilleri et al., 2006, p. 71).

6.8.11 Range hood

The New Zealand open source repository identifies the wattage of a range hood as 150 Watts. (Alterenergy, undated). Camilleri et al. (2006) establish that a range hood uses 0.4 Watts of standby power (Camilleri et al, 2006, p. 71). An estimate of the usage of a range hood is based on the usage of an oven. These appliances are typically run at the same time. GfK (2014) identifies an average cooking time of six hours per week (GfK, 2014). This equates to an additional 1.6 Watts a day. This figure is small in comparison to the average wattage identified and was not considered in the analysis.

6.8.12 Electric oven

Table 6.33 depicts the wattage estimate of an electric oven:

<i>Wattage</i>	3,000	2,150	1,900	2,400
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(Alterenergy, undated.)	(Energy Use Calculator, 2017k)

Table 6.33: Estimated wattages for an oven.

The range of wattages for an oven is estimated between 1,900 and 3,000 Watts. The average between these figures is 2,450 Watts. An assumption is made that 820 Watts, one-third of the average wattage, more reliably represents the operation of an electric oven (U.S Department of Energy, undated.b). Electric ovens are usually installed in a way that prevents the household

from easily switching off this appliance when in use. However, Camilleri et al. (2006) identify that, of the households measured, this appliance has no standby power (Camilleri et al., 2006).

6.8.13 Electric hob

A New Zealand supplier of electric hobs identifies that the larger ring operates at a maximum of 1,500 Watts, while the smaller ring operates at 1,000 Watts (Harvey Norman, 2017c). An assumption is made that an average household uses one large and one small ring when operating the appliance. This usage equates to a maximum wattage of 2,500 Watts. The appliance is controlled by a thermostat. One-third of the maximum wattage, 830 Watts, is used in the analysis to calculate the operational energy of an electric hob (U.S Department of Energy, undated.b).

6.8.14 Induction hob

A manufacturer, Whirlpool, identifies that a typical four ring induction cooktop has a separate wattage for each plate. The wattage ranged from 1,800 to 2,200 Watts per plate (Whirlpool, undated.). Similar to the electric hob, it is assumed that one large and one small ring are in use during the appliance's operation. This usage equates to a maximum wattage of 4,000 Watts. An induction hob is also controlled by a thermostat. 1,300 Watts is used to represent one-third of the maximum wattage (U.S Department of Energy, undated.b).

6.8.15 Electric range (hob and stove)

The electric range (hob and stove) wattage is estimated to be a combination of the electric oven wattage and the electric hob wattage. This totals 4,950 Watts of maximum wattage or 1,650 Watts of operation when controlled by a thermostat (U.S Department of Energy, undated.b).

6.8.16 Wood/coal range (hob and stove)

A New Zealand study titled "*Wood and Solid Fuel Heating in New Zealand*" presents the results of the solid fuel burner monitoring undertaken as part of the HEEP project. 244 houses were monitored at 10-minute intervals to estimate the overall heat output. This concludes that the consumption for the solid fuel stove in the HEEP houses that use a wood/coal range is 4,500kWh (Camilleri et al., 2007).

6.8.17 Electric grill

The nine sources analysed in the comparative study use various terminology to describe what could be an electric grill, though it was not clear. The wattage for an electric grill is estimated to be 2,400 Watts by a New Zealand retailer (Briscoes, 2011b). One-third of the maximum wattage more reliably represents the operational energy of the appliance so 800 Watts is used in the analysis for an electric grill (U.S Department of Energy, undated.b).

6.8.18 Mini oven

None of the open source repositories that were compared, establish the wattage of a mini oven. A New Zealand retailer identifies that this appliance has an average wattage of 2,400 Watts (Briscoes, 2011c). Similarly to the electric oven, the mini oven is controlled by a thermostat and so does not operate at the maximum wattage over the duration of usage. One-third of the maximum wattage, 800 Watts, is a more accurate figure to use in the LCA (U.S Department of Energy, undated.b).

6.8.19 Electric barbeque

Davis (2012) wrote an article titled “*Balcony BBQ: We test 5 hot outdoor electric grills*” (Davis, 2012). Table 6.34 depicts the brands and wattages he identifies. In accordance with ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b) no details of manufacturing information or specific appliance models are disclosed. The table only refers to the models as compared in the Davis (2012) study.

<i>Brand</i>	<i>Wattage</i>
Weber	1,560
Patio Bistro	1,750
Aussie	1,670
Cuisinart	1,500
Kalorik	1,440
<i>Table 6.34: Comparison of the wattage of five electric barbeques (Davis, 2012).</i>	

The wattage for an electric barbeque ranges from 1,440 to 1,750 Watts. The average wattage is 1,600 Watts. While this study is undertaken in the United States, a range of models are compared including Australian and Belgian models. This reference is a reliable source of information because the figures are obtained directly from the manufacturer and a range of electric barbeques is compared. One-third of the maximum wattage of 530 Watts is used in the

LCA to account for the thermostat control of this appliance (U.S Department of Energy, undated.b).

6.8.20 Charcoal barbeque

A study titled “*Woodfuel Flow Study of Phnom Penh, Cambodia*” identifies the following useful conversion (Thong et al., 1998, p. v):

1 kilogram of charcoal = 29MJ (Thong et al., 1998, p. v).

The study measures wood fuel flows over a six-month period where 84 per cent of the households measured use firewood and charcoal as their main source of cooking energy (Thong et al., 1998, p. iii). The following daily usage for charcoal cooking is identified:

<i>Place of interview</i>	<i>Household Size</i>	<i>Amount Used (kg)</i>
Wat Phnom	4	1.83
Russei Keo	4	1.83
Psa Silop	6	1.5
O’Russei	6	1.33
Bodeng	5	1.66
Wat Mohamontrey	4	2.5
Wat Ko	6	1.83
Olympic	4	1.17
Bodeng	4	1.33
Chhbar Ampeou	8	2.5
Toul Tom Pong	5	1.83
	Average	1.76

Table 6.35: Daily charcoal consumption (Thong et al., 1998, p. 5).

GfK (2014) identifies below that the average cooking time averages at six hours per week across the world for the main source of cooking. A charcoal barbeque is estimated to run for two hours a week to assist with day to day cooking so the New Zealand daily charcoal usage is estimated at 0.59 kilograms of charcoal (one-third of 1.76 kilograms). The wattage equivalent of a charcoal barbeque is estimated at 17MJ.

6.8.21 Fry pan

The following wattages are identified for a fry pan:

<i>Wattage</i>	1,200	1,240
<i>Source</i>	(ABS Alaskan, 2008)	(Alterenergy, undated.)

Table 6.36: Estimated wattages for a fry pan.

The wattage of a fry pan is estimated similarly by two sources. 1,240 Watts is chosen to represent the maximum wattage of a fry pan. This figure aligns closely with the data used in the LCA and is more reliable. Similarly to an electric grill, fry pans are also controlled by thermostats so 410 Watts is used in the LCA to calculate the operational energy of this appliance (U.S Department of Energy, undated.b).

6.8.22 Cooking appliance usage

Cooking usage is identified as six hours per week using a GfK study. The study interviews more than 27,000 people across twenty-two countries, and identifies an average cooking time between 4.9 and 7.6 hours per week (GfK, 2014) (see figure 6.3). One of the strategies GfK adopts is “*how do consumers behave and buy?*” (GfK, 2017). They consider appliance ownership and use when estimating the usage of cooking appliances.

Figure 6.3: Average cooking time in 22 countries as identified by GfK (2014).

The usage of an oven is estimated to be six hours a week based on the average cooking time (GfK, 2014). Hobs, range (hob and stove), and a range hood are assumed to be in use for the same amount of time as an oven. A microwave is in use for thirty minutes per day, every day of the year to assist with day-to-day cooking (Energy Use Calculator, 2016e; Warren Recc, 2016ab). The other smaller cooking appliances (barbeques, electric fry pan, rice cooker, grills, crockpot and bench top mini-oven) are assumed to run for two hours per week to assist with day to day cooking.

6.9 Space heating appliances

6.9.1 Electric blanket

Six sources identify the wattage of an electric blanket:

Wattage	200	200	200	400	177	75-100
Source	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(U.S Department of Energy, undated.b)	(Warren Recc, 2016ab)	(The Electric Blanket Institute, undated.a)

Table 6.37: Estimated wattages for an electric blanket.

The wattage of an electric blanket is estimated similarly by three sources (200 Watts), with the U.S Department of Energy appearing to estimate the wattage of a double electric blanket (400 Watts). The Electric Blanket Institute provides “a factual and unbiased consumer guide to electric blankets and electric mattress pads” (The Electric Blanket Institute, undated.b). The institute establishes the actual cost to run an electric blanket by identifying the wattage and usage. This cost was then compared to several other common household appliances to communicate the low running cost of this appliance despite the current understanding of the appliance usage (see figure 6.4) (The Electric Blanket Institute, undated.a).

Figure 6.4: Comparison of the cost to run an electric blanket against several common household appliances (The Electric Blanket Institute, undated.a). Prices in US dollars.

While three sources estimate the same wattage figure, it is difficult to discount the figures estimated by the Electric Blanket Institute. They identify the maximum wattage of a single electric blanket as 100 Watts. The Electric Blanket Institute identifies that an electric blanket uses between 75 and 100 Watts per side if dual controlled, so the wattage of a double electric blanket is estimated at 200 Watts. An electric blanket is controlled by a thermostat so 33 and

67 Watts more reliably represents the operation of a single and double electric blanket (U.S Department of Energy, undated.b). A single and double electric blanket are estimated to run for eight hours a night, during the colder autumn and winter months i.e. one hundred and eighty-two days of the year. This is based on a typical sleep pattern of eight hours per night (The Electric Blanket Institute, undated.a). An assumption is made that during these colder months, the electric blanket is left plugged in by household members, however, Camilleri et al. (2006) identify that an electric blanket has no standby power (Camilleri et al., 2006, p. 72). Hence, no additional operational energy is factored in for electric blankets outside operation hours.

6.9.2 Portable fan heater and bathroom wall fan heater

The following wattages are identified for a portable fan heater:

<i>Wattage</i>	2,000-3,000	2,400
<i>Source</i>	(Daft Logic, 2017b)	(Alterenergy, undated.)
<i>Table 6.38: Estimated wattages for a portable fan heater and a wall heater.</i>		

The range of wattages for a portable fan heater is estimated between 2,000 and 3,000 Watts. A figure of 2,400 Watts is chosen for the maximum wattage of this appliance. One-third of the maximum wattage (800 Watts) represents the operation of this appliance when controlled by a thermostat (U.S Department of Energy, undated.b). Camilleri et al. (2006) identify that heaters have little to no standby power (Camilleri et al., 2006, p. 72). A New Zealand supplier of heaters identifies that a wall fan heater (bathroom) is a similar sized portable fan heater fixed vertically (Bunnings Warehouse, undated.b). An assumption is made that a wall fan heater (bathroom) has the same wattage as a portable fan heater. A wall fan heater (bathroom) was assumed to run for one hour, every day of the year. This was based on the usage of a typical household of four, running the appliance for fifteen minutes after each shower.

6.9.3 Portable radiator heater and radiator heater

A retailer of heating appliances identifies the wattage of various radiant heaters. Two-bar models and three-bar models are compared, though the details of this comparison are omitted from this thesis in accordance with ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). These standards require that no manufacturing information or specific appliance models are disclosed. A range of wattages was identified between 800 and 2,400 Watts (Goldair, 2017b). The average maximum wattage is 1,600 Watts. One-third of the maximum wattage, 530 Watts, is used in the calculation of operational energy (U.S Department of Energy, undated.b).

6.9.4 Convection heater

The wattage and usage cost for eight convection heaters are compared:

<i>Power Rating</i>	<i>Cost Per Day</i>	<i>Cost Per Year</i>
450W	£0.28 (\$0.50)	£24.90 (\$44.57)
500W	£0.31 (\$0.55)	£27.67 (\$49.53)
750W	£0.46 (\$0.82)	£41.50 (\$74.29)
1,000W	£0.61 (\$1.09)	£55.33 (\$99.04)
1,500W	£0.92 (\$1.65)	£83.00 (\$148.57)
2,000W	£1.23 (\$2.20)	£110.66 (\$198.09)
2,500W	£1.54 (\$2.76)	£138.33 (\$247.62)
3,000W	£1.84 (\$3.29)	£166.00 (\$297.15)

Table 6.39: Power rating and usage cost comparison of various convection heaters. The original study presented the figures in GBP, which are converted here to NZD (Sust-it, 2017).

Utilising the UK average electricity rate of 15.37p and a usage of four hours per day for 90 days per year at maximum output, the study identifies a wattage range for a convection heater between 450 and 3,000 Watts. This is an average of 1,725 Watts. One-third of the maximum wattage is 580 Watts. This more reliably represents the overall usage of this thermostat controlled appliance (U.S Department of Energy, undated.b).

6.9.5 Obsolete radiator heater

The New Zealand open source repository is the only source which clearly identifies the wattage figure of an obsolete radiator heater. Alterenergy identified that a two-bar heater has a wattage of 2,400 Watts (Alterenergy, undated.). This figure is much larger than the figure identified above for a portable radiator heater so this figure makes sense in the calculation of operational energy. A thermostat controls the temperature at which the quartz tubes operate. One-third, 800 Watts, more reliably represents the operation of an obsolete radiator heater (U.S Department of Energy, undated.b)

6.9.6 Electric panel heater

Comparison of the wattage and operating cost of four-panel heaters (see table 6.40):

<i>Wattage</i>	<i>Cost per hour</i>	<i>Cost per month</i>
400W	11c	\$7.60
500W	14c	\$9.50
1,000W	28c	\$19.00
1,500W	29c	\$29.00

Table 6.40: Comparison of four-panel heaters. Costs per hour are based on the New Zealand 0.282c per kWh. All costs per month are based on a usage of three hours per day, every day of the month (Mitre 10, undated.a).

The range of wattages for an electric panel heater was estimated between 400 and 1,500 Watts when four-panel heaters are compared. This equates to an average of 950 Watts. This appliance also has a thermostat to control the temperature it operates at so 320 Watts is utilised in the calculation of operational energy (U.S Department of Energy, undated.b). The majority of the heating appliances are assumed to have a usage of six hours a day, one hundred and eighty-two days of the year, or half of the year in the colder autumn-winter months. This is based on a usage when most members of the household are at home from school or work (between 6 pm and 12 am).

6.9.7 Dehumidifier

Three sources estimate the wattage for a dehumidifier:

<i>Wattage</i>	350	275	350
<i>Source</i>	(Wholesale Solar, 2017)	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.41: Estimated wattages for a dehumidifier.

The wattage of a dehumidifier ranges between 275 and 350 Watts. 350 Watts is selected to represent the maximum wattage of a dehumidifier. This appliance is also controlled by a thermostat so 115 Watts (one-third of 350 Watts) is selected to calculate the operational energy of this appliance. The following usages are identified for a dehumidifier:

<i>Usage</i>	12 hours/day	4 hours/day
<i>Source</i>	(Warren Recc, 2016ab)	(Government of Delaware, undated.)

Table 6.42: Estimated usage figures of a dehumidifier.

The usage for a dehumidifier is estimated between four hours and twelve hours a day. Since the sources are reasonably close in terms of estimated usage, an average between the highest and lowest estimate of eight hours per day, every day of the year is used in the research.

6.10 Gas appliances

In the following section, gas appliances are presented collectively. The gas appliances explored in this study follow the definition of appliance as defined in chapter four. However, gas appliances are identified here are not as portable/handheld as many of the electric appliances identified in the LCIs dataset to this point. Gas appliances discussed in this section are:

1. Gas Range (LPG)
2. Gas Oven (LPG)

3. Gas Hobs (LPG)
4. Barbeque (LPG)
5. LPG heater

These five gas appliances are all found in either the heating or cooking categories as defined by EECa, and with the exception of portable gas heaters, most are often considered chattels in house construction. These are, however, still considered appliances as they are behaviour orientated in the manner in which these can be replaced. Gas cooking (unlike gas hot water heating or central heating systems) is a behavioural choice that household occupants often make depending on occupant preference and behaviour, much like the other appliances explored in this study. Hence all five of these gas-powered appliances are considered essential in measuring impact in the act of dwelling. Due to the calculation method, all of these gas appliances are discussed collectively.

6.10.1. Basic figures and assumptions for calculating usage

There is no single answer to the question of usage. To ascertain a nominal figure or a series of usage figures that represent low, medium and high use, some explanation is required to understand the varying usage observed in the data collected. There are a series of figures that have been used in the basic energy calculations (Ministry of Business, Innovation and Employment, 2015b, p. 31):

- Energy equivalent conversion: 1kWh = 3.6MJ;
- 1kg of New Zealand LPG = 1.856 litres of LPG (60:40 propane-butane mix);
- New Zealand LPG contains approximately 26 MJ per litre;
- A 45kg gas bottle contains about 84 litres of LPG or 2,212 MJ of energy.

Gas appliances, much like their electric counterparts, are rated in MJ or MJ per hour. However, this is not necessarily a measure of output. More accurately, this is a measure of the required gas input. The output is typically measured in kilowatts. The MJ inputs and kilowatt outputs are directly related but are affected by the efficiency of the appliance. For example, a 25 MJ heater may have an output of 6.2 kilowatts. This does not appear to make sense when dividing 25 MJ by 3.6 MJ the output would be expected to be 6.94 kilowatts, not 6.2 kilowatts. The difference in this example is a direct result of the efficiency of the heater. The heater in this example would be 89.3 per cent efficient. No gas appliance is one hundred per cent efficient

(Trelaor, 2015, p 238) which is why there is a Star rating system to judge the relative performance of different models.

6.10.2. Application to HEEP: Establishing measures and assumptions

To establish the operational energy of varying appliances from the case study data collected, the aforementioned usage figures are applied to every gas appliance used in each household. The HEEP data identifies five possible gas powered appliances that each household may use. These were:

1. Gas Range (LPG)
2. Gas Oven (LPG)
3. Gas Hob (LPG)
4. Barbeque (LPG)
5. LPG heater

There are some significant limitations to the figures this method generates. Any operational or embodied energy data calculated for gas appliances are limited to these five appliances; HEEP data only identified usage by the number of days in a month these appliances are used, therefore, hourly use per day for each appliance is an estimated assumption. For cooking time, six hours a week of use for cooking is established using a GfK study. Looking at 27,000 people from twenty-two countries, this study identifies average hours spent cooking in a week (GfK, 2014). Table 6.43 identifies the wattage and usage equivalent for gas appliances.

<i>Appliance type and capacity</i>	<i>Varied daily use and number of days a 45kg gas cylinder lasts</i>		
Gas Heaters	2 Hours/day	3 Hours/day	4 Hours /day
15MJ Heater	73 days	49 days	37 days
25MJ Heater	44 days	29 days	22 days
Gas Cooking	30 minutes/day	60 minutes/day	90 minutes/day
9MJ Burner	489 days	244 days	163 days
<i>Table 6.43: The gas cooking appliances, are assumed to be the same. A kerosene heater was assumed to be similar to an LPG heater.</i>			

6.11 Lighting

The following lamp types are identified in this study.

1. Incandescent Lamp (Portable and fixed)
2. Halogen Fixed Tungsten Lamp
3. Halogen (GU10) Lamp
4. CFL (spiral) Lamp

5. LED Lamp

6. Heat Lamp

An assumption is made that there is little difference between the light fittings in a household. The wattage of each lamp is identified before the usage is discussed below.

6.11.1 Incandescent lamp

Seven out of the nine open source repositories analysed in the comparative study identify the wattage of an incandescent lamp:

<i>Wattage</i>	50-100	60-100	40-100	40-100	60	60	40-100
<i>Source</i>	(Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)	(Alterenergy, undated.)	(Frequency Cast, 2016)	(Energy Use Calculator, 2017l)	(Warren Recc, 2016ab)

Table 6.44: Estimated wattages for an incandescent lamp.

The range of wattages for an incandescent lamp is estimated between 40 and 100 Watts. Most sources identified a wattage figure of 60 Watts that aligns with the ranges of the other sources. A portable lamp is often limited to a maximum wattage requirement of 60Watts, some small lamps going as low as 40 Watts (Warren Recc, 2016ab). For the purposes of this study, 60 Watt lamps are assumed for all portable lamps. A fixed lamp is used in ceilings and wall lights, these fixtures do not have the same lower wattage requirement, hence the wattage for a fixed incandescent lamp is estimated at the higher end of the scale at 100 Watts.

6.11.2 Halogen lamp

A New Zealand supplier of light bulbs identifies that the wattage of halogen bulbs range between 10 and 140 Watts. The average between these two figures is 75 Watts and is the figure used in the study to calculate the operational energy of this appliance both fixed and portable (Bunnings Warehouse, undated.c).

6.11.3 CFL and fluorescent lamp

The following wattages are identified for a Compact Fluorescent Lamp (CFL):

<i>Wattage</i>	11-30	11-30	14
<i>Source</i>	(Wholesale Solar, 2017)	(ABS Alaskan, 2008)	(Energy Use Calculator, 2017m)

Table 6.45: Estimated wattages for a CFL lamp.

The range of wattages for a CFL is estimated between 11 and 30 Watts. An average figure of 20 Watts is used in the analysis for both the portable and fixed lamp. An assumption was made that a domestic CFL and a domestic fluorescent lamp have similar wattages.

6.11.4 LED lamp

Three New Zealand lighting retailers are used to ascertain the wattage of LED lamps. They identify a range of wattages between 2.3 Watts and 18 Watts (Bunnings Warehouse undated.d; Mitre 10, undated.b; Ledrus, n.d). While no household in the HEEP study owned an LED lamp, this appliance has been rapidly developed today to increase energy efficiency (Yamada and Stober, 2015, p. 14). By the time this study is published, a lower wattage is likely to be achieved, so the wattage of an LED lamp is estimated at 4.5 Watts for use in future research.

6.11.5 Heat lamp

None of the nine open source repositories compared in the comparative study identify the wattage for a heat lamp. A New Zealand retailer is used to ascertain an accurate wattage figure. Bunnings Warehouse is one of two main home and garden retailers in New Zealand. They identified the typical wattage of a heat lamp as 275 Watts (Bunnings Warehouse, undated.e). Similarly, to a wall fan heater, the usage of a heat lamp was estimated to be one hour a day, every day of the year.

6.11.6 Lighting usage

All lighting is estimated to run for an average of 4.5 hours a day, every day of the year based on usage figures supplied by the Energy Use Calculator and Warren Recc. Both sources identify the same usage across different lighting types so the same approach is utilised in this research (Energy Use Calculator, 2017l, m; Warren Recc, 2016ab). The usage for a lamp is found to be the same as the usage of a television. These figures make sense as these appliances are typically used in parallel when most the household is home and awake.

6.12 Garage and garden appliances

6.12.1 Garage and garden appliance usage

The Lawn Institute undertook a study to identify the average time it takes to mow a typical home lawn. They identify that an average American lawn is 929 square metres and takes

approximately thirty minutes to mow. Estimating that the growing season is across seven-months of the year, they identify the typical usage of an electric lawnmower and weed eater at eleven hours per year (The Lawn Institute, 2016). A study titled “*Minimum vs Maximum: size and the New Zealand house*” identifies that yard areas range from 240 metres squared to 892 metres squared (Marriage, 2010, p. 1). This equates to an average yard size of 566 metres squared in New Zealand. If 929 square metres takes eleven hours per year to mow, then 566 square metres takes approximately seven hours per year to mow. Power tools are assumed to run for seven hours per year like a lawnmower and weed eater.

6.12.2 Gas lawnmower and weed eater

A study titled “*Life Cycle Assessment of Lawnmowers: Two mowers case study*” as discussed in chapter five, identifies that a typical petrol lawnmower uses 219.75 litres of petrol over 250 hours, this equates to 0.88 litres of petrol every hour. When operated for seven hours a year this equals 6.16 litres of petrol. An assumption is made that the weed eater uses half as much petrol as a lawn mower. A New Zealand study titled “*Mitigating the Impacts of Climate Change on the Built Environment*” identifies the following useful conversion:

1 litre of petrol equals 32.2 MJ (Hargreaves, Rachael, 2003).

The study provides a mitigation tool to assist the New Zealand construction industry to better prepare for the effects of climate change on the built environment. the tool is a New Zealand-specific calculator which enables individuals to calculate their energy-related carbon emissions. The wattage equivalents of a gas lawn mower and gas weed eater are 198.3 MJ and 99.1 MJ respectively.

6.12.3 Electric lawnmower

A retailer of home and garden appliances identifies a range of wattages for an electric lawnmower. Five different models have a wattage between 400 and 1,800 Watts (Bunnings Warehouse, n.d.f). The models are not reported here as required by ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). A median wattage of 1,100 Watts is used in the analysis.

6.12.4 Electric weed eater

The following wattages are identified for the weed eater:

<i>Wattage</i>	450	300-500	450
<i>Source</i>	Wholesale Solar, 2017)	(Daft Logic, 2017b)	(ABS Alaskan, 2008)
<i>Table 6.46: Estimated wattages for a weed eater.</i>			

The wattage for a weed eater is estimated between 300 and 500 Watts. Two sources estimate the same wattage of 450 so it is used in the LCA for an electric weed eater.

6.12.5 Electric power tools

Four open source repositories report on the wattage of a range of electric power tools. The wattage varied significantly from the highest and lowest estimate of wattage so the estimates are compared in the table below for clarity:

<i>Power tool</i>	<i>Wattage</i>	<i>Source</i>
Electric drill	250-1,000	(Wholesale Solar, 2017; ABS Alaskan, 2008)
Disc sander	1,200	(Wholesale Solar, 2017; Daft Logic, 2017b; ABS Alaskan, 2008)
Belt sander	1,000	(Wholesale Solar, 2017; Daft Logic, 2017b; ABS Alaskan, 2008)
Chain saw	1,100	(Wholesale Solar, 2017; ABS Alaskan, 2008)
Band saw	1,100	(Wholesale Solar, 2017; ABS Alaskan, 2008)
Circular saw	900-1,400	(Wholesale Solar, 2017; ABS Alaskan, 2008)
Rechargeable power tool	13	(U.S Department of Energy, undated.b)
Cordless drill charger	70-150	(Daft Logic, 2017b)
<i>Table 6.47: Estimated wattages for electrical power tools.</i>		

The range of wattages for a power tool is estimated between 13 and 1,400 Watts. The HEEP data collected did not identify specific types of power tools so it is unclear what the most common power tool is in New Zealand households. Each source also identified a different figure so an average figure of 700 Watts is used to reflect all possible power tool types.

6.13 Summary

In order to better calculate the operational energy of each appliance in New Zealand households, the HEEP study measured the wattage and use of many household appliances. This was, in part, to understand how appliance impact relates to household impact. This requires the embodied energy (as established in chapter five) and the operational energy of the appliances to be calculated. Table 6.48 summarises the figures identified for the wattage and usage of each

appliance. These figures are used to calculate the operational energy for appliances, identified in the New Zealand HEEP study, for this thesis.

Appliance	Wattage	Hours/Day
<i>General/small portable appliances</i>		
Vacuum cleaner	700	0.003 (40 minutes per week)
Sewing machine	100	0.0008 (7 hours per year)
Cupboard heater	6	24
Heated towel rail	32	12
Extraction fan	40	2
Heated fish tank	50	24
<i>Entertainment Appliances</i>		
Television analog <40"	100	4.5
Television analog >40"	180	4.5
Television CRT	80	4.5
Television DLP	200	4.5
Television ED HDTV <40"	170	4.5
Television ED HDTV >40"	250	4.5
Television plasma	320	4.5
Television LCD	200	4.5
Television LED	80	4.5
Computer	300	5
Video games player	120	5
Video player	64	4
Radio cassette layer	45	1
Stereo	200	1
TV decoder	20	24
<i>Washing/drying appliances</i>		
Iron	370	0.009 (1.5 hours a week)
Dishwasher	400	3
Washing machine	570	0.94 (56.5 minutes per day)
Tumble dryer	980	0.006 (1 hour per week)
Cabinet dryer	520	0.006 (1 hour per week)
<i>Kitchen/cooking appliances</i>		
Refrigerator	80	24
Combination fridge freezer	100	24
Deep freeze	80	24
Toaster	460	0.006 (1 hour a week)
Electric jug (kettle)	2,400	0.25 (15 minutes a day)
Coffee maker	750	0.25 (15 minutes a day)
Food processor	375	0.006 (1 hour per week)
Mixer	300	0.006 (1 hour per week)
Bread maker	180	0.02 (15 hours per month)
Rice cooker	150	0.01

		(2 hours per week)
Crockpot	230	0.01 (2 hours per week)
Microwave	750	0.5 (30 minutes a day)
Waste master	450	0.25 (15 minutes a day)
Range hood	150	0.04 (6 hours a week)
Electric range (hob and stove)	1,650	0.04 (6 hours per week)
Gas range (hob and stove)	9MJ	0.04 (6 hours per week)
Wood/coal range (hob and stove)	4,500kWh	0.04 (6 hours per week)
Electric oven	820	0.04 (6 hours per week)
Gas oven	9MJ	0.04 (6 hours per week)
Separate electric grill	800	0.01 (2 hours per week)
Separate gas grill	9MJ	0.04 (6 hours per week)
Electric hobs	830	0.04 (6 hours per week)
Gas hobs	9MJ	0.04 (6 hours per week)
Induction cooking	1,300	0.04 (6 hours per week)
Bench top mini-oven	800	0.01 (2 hours per week)
Barbeque (LPG)	9MJ	0.01 (2 hours per week)
Barbeque (charcoal)	17MJ	0.01 (2 hours per week)
Barbeque (electric)	530	0.01 (2 hours per week)
Electric fry pan	410	0.01 (2 hours per week)
<i>Space heating appliances</i>		
Single electric blanket	33	4 (8 hours, for half the year)
Double electric blanket	66	4 (8 hours, for half the year)
Portable fan heater	800	3 (6 hours, for half the year)
Wall fan heater (bathroom)	800	1
Electric radiator	530	3 (6 hours, for half the year)
Portable electric radiator	530	3 (6 hours, for half the year)
Portable convection heater	580	3 (6 hours, for half the year)
Obsolete electric fan/bar radiator	800	3 (6 hours, for half the year)
Electric panel heater	320	3 (6 hours, for half the year)

Portable kerosene heater	20MJ	3 (6 hours, for half the year)
LPG heater	20MJ	3 (6 hours, for half the year)
Dehumidifier	115	8
<i>Lighting</i>		
Incandescent lamp fixed	100	4.5
Incandescent lamp portable	60	4.5
CFL (spiral) lamp fixed	20	4.5
CFL (spiral) lamp portable	20	4.5
Halogen fixed tungsten lamp	75	4.5
Halogen portable lamp	75	4.5
Fluorescent lamp	20	4.5
Fluorescent lamp portable	20	4.5
LED lamp	4.5	4.5
Heat lamp	275	1
<i>Garage/garden appliances</i>		
Gas lawnmower	198.3	0.0007 (7 hours per year)
Electric lawnmower	1,100	0.0007 (7 hours per year)
Gas weed eater	99.1	0.0007 (7 hours per year)
Electric weed eater	450	0.0007 (7 hours per year)
Electric power tools	1,000	0.0007 (7 hours per year)
<i>Table 6.48: Wattage and usage figures for each appliance to calculate operational energy.</i>		

6.14 The next step: Chapter seven

To establish total impact of household behaviour, appliance usage and choice, chapter seven presents the key results of the investigation in household behaviour. Using the analytical framework identified in chapter four, chapter seven will present the significance of appliance number and show appliance impact compared to house impact for all households measured in the HEEP study.

Chapter seven will also present the CO₂ equivalent emissions associated with appliance impact and present the significance of these emissions compared to the reduction targets, identified in chapter three. Towards the end of the chapter, chapter seven will conduct a possible emissions reduction study, ascertaining the type of behavioural changes that could best achieve significant reductions and will address the thesis question posited at the beginning of this research.

Chapter Seven

Research Results and Discussion

7.1 Key results of the investigation into household behaviour

This chapter presents the key results of the investigation in three main sections that address the thesis question. These sections deal with the significance of appliance number; a comparison of appliance impact verses house impact, looking specifically at energy expenditure; and finally, CO₂ emissions of appliance ownership and operation.

Earlier in this thesis it was theorized that there could be a common phenomenon where ownership of many extra appliances of the same kind could potentially distort how operational energy, for some appliances, is affected, as discussed in the hypothetical example of the hairdryer (see chapter three). In order to ascertain whether or not this phenomenon is a prevailing behavioural trait, the first section of this chapter identifies whether or not appliance numbers are in fact significant, in regards to having an increased use, due to owning multiples of the same appliance. This is achieved by mapping all appliance usage using the *Proportional* and *Unchanged, effect on operation* formulae presented earlier in chapter four. Any substantial variation (or emerging patterns) between the results of these two formulae would identify whether or not a significant number of households, which choose to have multiples of the same appliance, are increasing consumption by operating these appliances as well as increasing

embodied energy by owning them. The aim of this analysis is to determine the extent to which ownership of multiples of the same appliance affects total impact.

Having established the significance of appliance number, the second part of this chapter identifies the results of the energy analysis of measured appliance ownership and operation. In this section, the total energy expenditure, measured in megajoules, of each household's appliance use and operation, is identified as a relative percentage when compared to the total operational and embodied energy footprint of the house.

The final part of this chapter identifies the results of the total CO₂ equivalent emissions associated with appliance operation. Using the total number of case studies, this section calculates a nationwide household behaviour-based CO₂ emissions figure based on the total number of households in the New Zealand housing stock. This total emissions figure of behaviour in the *act of dwelling* is compared to the total CO₂ equivalent emissions figure of New Zealand to identify the importance of household behaviour, relative to total emissions from every sector. Based on these results, possible reductions are postulated and presented against the renewable electricity mix data presented in chapter three and the emissions reductions target set during the Paris accord. Towards the end of this chapter, all of these results are discussed, considering the practicality of any proposed changes and their potential limitations.

7.2 Significance of appliance numbers

A question of appliance number emerged early in the analysis of the raw data obtained from the HEEP study. It was theorized that due to the manner in which varying appliances function, ownership of more than one appliance would not necessarily increase operation. This possible lack of correlation between the operational energy consumed and the increased number of the same appliance challenges a conventional life cycle assessment, which would establish a figure for the embodied energy of an appliance and a figure for the operation associated with this embodied energy. This conventional method, or proportionally increasing method (see chapter three), would increase the operational energy of any appliance if that appliance number increased, regardless of whether or not the operational energy was increased. In its simplest description, with this method the relationship between the embodied energy and operational energy is relative. This essentially means that both would increase by the same factor, *i.e. if raw materials to make 1 toaster = x and operational energy = y, 2 toasters equal 2x and the*

operational energy also increases to $= 2y$. As identified in chapter four, this *Proportional* calculation is represented by the following formula.

$\text{Embodied energy} + \text{Operational} = \text{Total Impact}$ $\left(\sum_{i=1}^{n_{\text{appliance}}} EE_i \right) + \left(\sum_{i=1}^{n_{\text{appliance}}} OE_i \right) = \text{Total Impact}$
- Equation 2

It is possible that ownership of several examples of a single appliance might not increase consumption proportionally. In response to this, an analytical framework was developed (see Chapter four) that would present an accurate measure of the *effect on operation* an increase in appliance number could have, depending of course, on the type of appliance and its method of use (as identified by the hair dryer example in chapter three).

In a life cycle assessment of approximately four hundred households with varying types and numbers of appliances, it would be very difficult to ascertain whether or not the implications of owning multiple appliances are potentially significant on household energy for a substantial number of case studies. Therefore, in order to see whether or not this is significant, both the *Proportional* and *Unchanged* formulae are applied to all appliances in each case study. The fundamental difference between these two formulae is how the operational energy is calculated. The *Proportional* formula would multiply the operational energy by the number of appliances, but the *Unchanged* formula would only consider the operational energy for the first appliance.

In this method when the appliance number is increased the operational energy is not affected and is independent of the embodied energy increase, *i.e. raw materials to make 1 toaster = x and operational energy = y, 2 toasters equal 2x but in the Unchanged scenario the operational energy still = y*. As identified in chapter four, this *Unchanged* calculation is represented by the following formula.

$\text{Embodied energy} + \text{Operational} = \text{Total Impact}$ $\left(\sum_{i=1}^{n_{\text{appliance}}} EE_i \right) + OE_{\text{original total}} = \text{Total Impact}$
- Equation 3

This form of assessing impact suggests that if the households examined in the study do not have multiples of the same appliances, there will not be any variations observed between the appliance impact results of the *Proportional* and *Unchanged* graphs. Variations or possible patterns of variations in energy expenditure, if observed, could indicate that multiple appliance numbers are potentially significant on household energy for a substantial number of case studies. In order to substantiate this, the results of the first formula, the *Proportional* formula analysis, are presented in figure 7.1.

To compare appliance impact with the impact of house construction and operation, a per meter square figure is used from Vale and Vale (2009) for house construction and operation for the full life of the house (assumed here as fifty years). Because all appliances have varied lifespans, a per annum impact figure is multiplied by fifty to ascertain an impact figure for each appliance for the life of a house. Once these are separately calculated in this manner, the sum total of all appliance impacts of each household, examined in this study, is established, these are the figures plotted against the total impact of a house in figure 7.1. Based on the results of the *Proportional* formula, which is applied to every single appliance in every case study, figure 7.1 suggests that

eighty-nine per cent of all households fall within the red zone shown in the graph. This indicates that these households have an appliance footprint (embodied and operational energy) that is equal to at least fifteen per cent of the overall footprint of the house.

Figure 7.1 also incorporates a red dashed line, marking the threshold of twenty-five per cent of the house construction and operation for the life of the house. If the appliance footprint of any household falls on, or above, this line, this indicates that the appliance footprint is equal to or above twenty-five per cent of the footprint of the house itself. The *Proportional* formula data graphed in figure 7.1 suggests that approximately forty-four per cent of the total households are above the red dashed line and thus have a significant appliance footprint equal to or above a quarter of the footprint of the house itself. Finally this graph also shows that approximately five per cent of the total households in the study have an appliance footprint that is equal to or above forty per cent of the total footprint of the house. Some reach levels almost as high as sixty per cent of the footprint of the house. In order to establish the significance of owning multiples of the same appliances, the results of the *Unchanged* formula, which are again applied to all households and appliances, are presented in figure 7.2. This includes operational energy of the first appliance then limits the effects of multiple appliance ownership to embodied energy only.

These results show that sixty per cent of the total households have an appliance footprint that is equal to at least fifteen per cent of the footprint of the house in its construction and operation; fifteen per cent have an appliance footprint equal to or above a quarter of the footprint of the house itself; and just over 0.5 per cent of the total (two households), have an appliance footprint that is forty per cent or more. At first glance these figures suggest that the results are somewhat similar and as shown by the side-by-side comparison (below) the variations seem marginal, the Unchanged formula suggesting a denser plot.

Figure 7.3: Comparison of Proportional results (left plot); Unchanged results (right plot).

However, when plotted together, as shown in figure 7.4, the data depict an emerging pattern in the variation between the results of using these two formulae. When plotted together the results show, unsurprisingly, that the *Proportional* figures (red data series) are all higher than the *Unchanged* figures. However, the scale of the data presented, and the total number of case studies, makes this more difficult to see at first glance.

Figure 7.4: Results from figures one and two are plotted here together to observe patterns of variation.

This can be attributed to the vast difference of appliance impact between different households due to the innumerable behaviour choices households make. Some have an appliance impact as little as five per cent, while houses in the same data set have results as high as sixty per cent. However, further scrutiny of this data identifies that almost every single household in the study pool showed an increase in appliance impact when the results of the *Proportional* formula are compared to those from the *Unchanged* formula.

Unlike the first graph of conventional application of impact assessment, where each appliance is assumed to be in operation if owned, the *Unchanged* data plots (shown in figures 7.2 and in red in figure 7.4) identify the impact of increased ownership of appliances.

Examination of the raw data produced by these formulae identified that out of the three-hundred and ninety-four households surveyed, nine households had no variation in the results of the *Proportional* and the *Unchanged* calculations. This suggests that these nine households are the only cases in which there are no multiple appliances present. An interesting observation here is that all of these households are in relatively small houses, ranging between seventy-six and a hundred and thirty-eight square metres.

In spite of this, the data did not suggest that houses within this size range were in general likely to have fewer multiple appliances, as there were a total of seventy-seven other case studies in the study pool that ranged between seventy-six and a hundred and thirty-eight square metres. Furthermore, the nine households which did not own multiple appliances were not the smallest in the study pool. There were another thirty-three households that ranged in size between fifty-one and seventy-six square metres.

To identify any relationships in ownership of multiples of the same appliance, the total impacts, presented here, as percentage differences of the two formulae, are plotted in figure 7.5, systematically arranged by house area.

Figure 7.5: Per cent increase in results of the *Proportional* formula and the *Unchanged* formula. Ordered from smallest house area to largest.

The erratic impact results, and consistently fluctuating results of the percentage difference between the *Unchanged* and *Proportional* data, suggest that house area has very little bearing on the presence of multiples of the same appliance. All of the data plots presented, in figures 7.1 to 7.5, identify that nearly all (ninety-nine per cent) of the households in the study pool have more than one of the same appliance. However, both the *Proportional* and *Unchanged* formulae results shown in this chapter so far are extreme scenarios. This is because in practice an increased number of the same appliances will neither mean that the operation will remain unchanged nor will it proportionally increase for all appliances as discussed earlier in chapter four.

7.3 Appliance impact v house impact

In order to determine tangible results of appliance impact, compared to house impact, the results of applying the *Proportional*, *Unchanged* and *Unknown Increase* formulae are presented in this section. Having established that there is a potential to have a bigger impact by simply having more of the same appliance and also that ownership patterns suggest that this is a behavioural trait amongst many households (in the previous section), it is anticipated that the results of applying the three formulae will produce more accurate findings that are somewhere between the *Proportional* and *Unchanged* data graphs presented earlier. To that end, each formula is applied based on observations of how varying appliances function and what the *effect on operation* will be if there are multiples of the same appliances. As identified in chapter four,

appliances are characterized by HEEP and EECA based on house design and operation, they are categorised as heating appliances, cooking appliances, etc. (see chapter four). In order to incorporate the measurement of usage and behaviour, the *effect on operation* approach was postulated that established the three formulae and consequent impact categories.

Figure 7.6 shows an appliance category diagram of how each appliance is categorised into the *effect on operation* formulae/impact categories (for a larger view of this diagram and list views, see appendix B). In the heart of the diagram the three impact categories stem outwards, first, to the HEEP defined categories and then to the individual appliances. Presenting this diagram in this manner illustrates interesting patterns of the types of appliances that the new impact categories differentiate. The most notable observation is that nearly every single HEEP category is broken down into the three *effect on operation* impact categories.

Figure 7.6: Appliance category diagram. Observed function, effect on operation formulae categories. Linked with HEEP and EECA defined categories. See appendix B, for a larger view of this diagram and list views.

This suggests that the various manners in which appliances are operated are inherently unique, and the three formulae are present in all HEEP categories. There are only two distinguishable HEEP categories that are not observed in all three formulae, these are the lighting and washing categories.

Based on number of washing loads, discussed earlier in chapter six, the washing appliances' usage is consistently observed to fit the *Unchanged* impact category, the lighting appliances category, identified in the *Proportional* impact category, is an area that merits further research as lighting use observed in the HEEP data only identified number of lights in a household. The data collected simply established that all of the lights identified in a household were constantly in use, based on nominal household occupation. More in-depth data collection, measuring more portable lighting appliances, may indicate there could likely be a number of lighting appliances that would fit into the *Unknown Increase* category shown in figure 7.6.

In order to now establish a more accurate image of appliance impact in comparison to house impact, all of the impact figures for appliances can be assessed using the *effect on operation* approach. To do this precisely, all appliances allocated to the three impact categories depicted in figure 7.6, are calculated based on their corresponding formulae. However, all of the appliances in the *Unknown Increase* category are assessed using the *Unchanged* formula. As discussed in chapter four, this is because of the unknown measure (x , see equation four) identified in the *Unknown Increase* formula (equation four).

$Embodied\ energy + Operational = Total\ Impact$ $\left(\sum_{i=1}^{n_{appliance}} EE_i \right) + x(OE_{original\ total}) = Total\ Impact$
- Equation 4

Without specific measurement of how much more an extra unit of the same appliance is used, it would be impossible to determine the effect any extra appliances (that cannot be defined under the *Proportional* impact category) may have on appliance operation.

The potential impact that appliances in the *Unknown Increase* category may have on total impact is discussed in chapter four. Due to the manner in which appliances can be used, by simply having one more of certain appliances in the *Unknown Increase* category could

potentially be responsible for an increase as insignificant as one per cent, while other appliances in this category could be responsible for more than two times the operation of one appliance.

As discussed in chapter four, a fundamental characteristic of all appliances in the *Unknown Increase* category is that there is an increase in operation if more than one appliance is used. Operation in this category never remains unchanged although it may not increase proportionally. For this reason, any results identified in this section, while being a more accurate image of total impact, still have a potential to be higher.

This is again an area for further research. Scrutiny of appliance numbers and possible operation increases for all the appliances in the *Unknown Increase* category is speculated on in the final chapter of this thesis. For any future application of these formulae, the further research section of the final chapter will also posit a theory for measuring the *unknown increase* for which any appliances may be responsible. The results of the appliance impact assessment, using the *effect on operation* formulae are presented in figure 7.7. Based on the results of the *effect on operation* formulae, figure 7.7 suggests that eighty-four per cent of all households fall within the red zone shown in the graph. This zone, as identified earlier, indicates that these households have an appliance footprint that is equal to at least fifteen per cent of the footprint of the house.

The *effect on operation* formula analysis graphed here shows that approximately forty per cent (38.3 per cent) of the total households are above the red dashed line, and thus have an appliance footprint equal to or greater than one-fourth of the footprint of the house itself. Finally this graph also shows that just over two per cent (2.3 per cent) of the total households in the study have an appliance footprint that is equal to or above forty per cent the total footprint of the house.

The impact assessment of household behaviour, in figure 7.7, is specifically based on observed operation from the data collected. Here, all appliances that would have a proportional operational response to an increase in appliance number are calculated accurately. All other appliances are categorized as *Unchanged*. This is particularly significant as eighty-four per cent of all of the case study households are within the red zone. This is only a five per cent shift from the extreme example (figure 7.1) of all appliances having a proportional response.

As shown in figure 7.8, the highest number of households (where appliance impact is equal to at least “15% of house impact”) shows a very small shift from the extreme example, in which all appliances that increased in number increased their operation proportionally. This relatively small shift in the final results suggests that the types of appliances that are increasing in number, are in fact those that lie predominantly within the *Proportional* category as theorized in chapter

four. This suggests that having more is directly resulting in using more for approximately eighty-four per cent of the households assessed in this study.

However, figure 7.8 also identifies a significant “class of behaviour”. There is an immediate difference observed for the households in the three categories of appliance impact comparison, shown in figure 7.8. The relatively small percentage of households that have an appliance impact equal to or greater than forty per cent, have almost no change in impact figures reported in the extreme example results. Because there is almost no detectable difference between the *unchanged* or *proportional* results and the final results, this data suggests that these households are not necessarily using or owning multiples of the same appliances, they may be simply large users of many varied appliances.

In order to establish any patterns in occupancy or house size, figure 7.9 identifies the house areas, total occupancy and number of children (if any) in each of the high user households. This includes nine households with an appliance impact equal to or greater than 40% of house impact, and also another nine households just under 40% (households equal to 39% are also included in this data plot). In all of these households, just under half have between one and four children. This is not a large contributing factor to the large appliance usage households as the remaining households did not have any children.

Figure 7.9 also identifies that the number of total occupants in these households ranges from one person to the relatively large occupancy of nine persons. This indicates that the total occupancy of the house appears to have little or no effect on the higher appliance impact when compared to house impact.

Conversely, an intriguing pattern observed in figure 7.9 is the range of house areas. While these are significantly different, ranging from fifty-eight square metres to one hundred and twenty-five square metres, these house sizes are not the biggest in the study. Out of the three hundred and ninety-four case studies assessed, one hundred and thirty-eight households are bigger than the largest house size identified in figure 7.9 (one hundred and twenty-five square metres). Ten of the biggest houses in the study range from as much as two-hundred and thirty square metres to as much as three hundred and fifteen square metres in area.

This is noteworthy because a significantly higher appliance impact in comparison to house impact could be expected of the smallest house sizes examined in this study but these households have a diverse range of house sizes which are not the smallest in the study. At first glance this data seems to infer that house size has little or no bearing on the behavioural choices made in appliance ownership or use.

In order to substantiate this and determine whether or not total appliance impact is affected by house size, figure 7.10 identifies total appliance impact over the life of the house (fifty years as identified by *Vale and Vale, 2009, p. 166*). This data is plotted against the area of the house in figure 7.10. The households with an appliance impact equal to or greater than forty per cent are plotted in red here. For consistency these also include the nine households on the thirty-nine percentile.

When compared to the initial appliance number comparison study, this study found that the nine households that had no variation in the results of the *Proportional* and the *Unchanged* calculations are included in the eighteen high appliance impact households shown in figure 7.10. This means that the single appliance households, identified earlier in this study are included in the red data plot. As shown in figure 7.10, the majority of these households have appliance impacts that are equivalent to the appliance impacts of houses that are more than three times their size.

Even though the large range of house sizes initially appeared to indicate house size was not relevant, the data plot in figure 7.10 suggests this may not be accurate. Despite the fact that there are many houses that have an equal or smaller floor area, houses with an impact that is forty per cent or more than the impact of the house are at the lower spectrum of the house sizes investigated. The data presented in figure 7.10 alludes to the possibility that house size may have some effect on appliance impact, however, this is not immediately evident in this data plot.

To investigate this further and to ascertain the extent to which house size affects the impact of appliances, the impact percentages discussed earlier of appliance impact compared to house impact are presented in figure 7.11 individually to observe any common patterns between all three grouped classifications. As shown in figure 7.11, these classifications are: appliance impact equal to fifteen per cent of the house impact, appliance impact equal to greater than twenty-five per cent of house impact, and appliance impact greater than or equal to forty per cent of the house impact.

The impact percentages comparison in figure 7.11 identifies that there is a distinct pattern of behaviour in all percentage comparisons. For all of the households, there is a correlative relationship with house size and appliance impact. All of these also suggest that there are similar trends in each grouped classification. These trends suggest that the behaviour of all appliance use increases with the size of the house. However, for the majority of households examined there is a range of appliance impact, where some smaller house sizes have an appliance impact that is the same as much bigger house sizes. This suggests that although bigger houses tend to increase appliance impact in terms of total GJ of consumption, the behavioural impact in small houses when compared to most of the bigger houses is relatively the same.

The major limitation here is of course that there are a series of appliances that fall in the *Unknown Increase* category, as discussed earlier. These would inevitably increase usage further and may well be greater than what is seen here in the final results.

7.4 CO₂ emissions of appliance ownership and operation

At the beginning of this thesis, chapter one posited a hypothesis that proposed that behaviour is an integral variable to measure the sustainability of a household. This hypothesis suggested that household choices had the potential to heavily impact the total embodied energy and the operational energy of the household. This hypothesis also theorized that a change in behaviour could in fact result in significant reductions in New Zealand's CO₂ emissions.

In order to investigate these theories, the CO₂ equivalent emissions produced in the operation and manufacture of all household appliances was measured. As identified in chapter four, the LCA study focuses on measuring both the total footprint of the energy expenditure, measured in megajoules, and also the CO₂ equivalent emissions produced by each household's appliance use and operation. Having presented the results of the energy footprint analyses in the first two

parts of this chapter, this part of the chapter identifies the results of this CO₂ accounting study in order to appropriately address the question of possible reductions, posed in chapter one.

The CO₂ equivalent analysis is broken down into the New Zealand specific measurement of the CO₂ produced in the operation of household appliances and the more energy intensive CO₂ emissions associated with the manufacture (often overseas) or the embodied energy of said appliances. The embodied energy of these appliances is not normally calculated in New Zealand CO₂ emissions reporting, as discussed in chapter three, therefore any proposed reductions in New Zealand emissions will not include embodied energy reductions. However, the CO₂ reductions, explored for the embodied energy, will be presented towards the end of this thesis, in order to identify the effect any change in behaviour may have on foreign, or imported, embodied energy.

7.4.1 Calculated CO₂ emissions: measured for 394 households

The *effect on operation* formulae, used earlier in the impact analysis, measured energy expenditure based on how varying appliances are utilized when there are multiples of the same appliance in a household. These formulae are used for varying appliances based on how the use of more than one of the same appliance is likely to affect total operation. Operation is directly linked to the amount of CO₂ produced, which means usage will have a similar effect on the total CO₂ emissions figure associated with appliance ownership and operation. Therefore, the *effect on operation* formulae are again used to measure CO₂ equivalent emissions, produced by these appliances and the observed operation patterns.

The CO₂ equivalent emissions analysis established that the total emissions produced as a result of the operation of appliances (i.e. not including the embodied energy used to manufacture them), in the three hundred and ninety-four households observed, was just over half a million kilograms (655,483 kg) of CO₂ equivalent emissions for one year.

Using the aforementioned total emissions figure, established for the case study household appliances, an estimated total for the entire country can now be identified by applying a representative household CO₂ figure to all households in New Zealand. According to the latest census records, the total number of households in New Zealand, as identified by statistics New Zealand as of November 2014, was just over one and a half million (1,549,890) households (Statistics New Zealand, 2014). In order to ascertain the total estimates for CO₂ produced by

household behaviour for every household in New Zealand, an average household emissions value of just over one thousand, six hundred kilograms (1,664 kg) per annum is established. This figure of yearly emissions is established by calculating the average yearly household CO₂ production figure of all the case study households observed in the CO₂ study.

This CO₂ emission figure for a single New Zealand house is multiplied by the total number of households identified by statistics New Zealand. Hence the combined total CO₂ emissions, observed in the act of dwelling (behaviour or the choices made in the household) for all of New Zealand, is identified at just over two and a half million tonnes (2,579,017 tonnes) per annum.

Established earlier in chapter three, the total CO₂ equivalent emissions produced in New Zealand were approximately eighty-one million tonnes in the year ending 2014. In order to understand the significance of the abovementioned national estimate of household behaviour, figure 7.13 identifies the proportional relationship this yearly total has in comparison to total New Zealand emissions observed in 2015.

As identified in chapter one, figure 7.13 suggests that the total emissions produced as a result of household behaviour and the choices made in the manner in which appliances are operated, is comparatively small given that total household operation is a very small part of the energy sector. These results suggest that the choices made in a household in the act of dwelling (*the behavioural choices of how much to own or the number of appliances to use*) is responsible for three percent of the nation's total CO₂ emissions every year. At just over two and a half million tonnes compared to current⁸ yearly CO₂ equivalent emissions of eighty-one million tonnes, the estimates of CO₂ equivalent emissions calculated in this study suggest that the effect of behaviour in the act of dwelling is very small compared to other sectors of industry. However,

⁸ The "Current" emissions value is establish in chapter three, and is defined as the gross CO₂ equivalent emissions reported by the Ministry for the Environment for the year ending 2014. The current CO₂ emissions value is therefore, 81,100,000 tonnes (gross).

in order to address the thesis question posed in chapter one, one of the main uncertainties is yet to be defined; can behavioural change make a significant change in the impact of the existing housing stock? Although the impact of behaviour is relatively small, the following section identifies whether or not this impact be significantly reduced.

7.4.2 Reductions target vs household behaviour emissions

In order to explore any viable or significant CO₂ reductions, the first step is to ascertain the reduction targets set by the Kyoto protocol discussed earlier in this thesis. As identified in chapter three, the New Zealand government submitted an addendum to the original agreement, formed as a result of the Kyoto Protocol, to reduce greenhouse gas emissions by thirty per cent below 2005 levels by 2030. This target is equivalent to eleven per cent below 1990 levels by 2030 (Ministry for the Environment, 2016b).

The New Zealand *Greenhouse Gas Inventory* report, identifies that New Zealand's gross CO₂ equivalent emissions were just over sixty million tonnes (60,600,000 tonnes) for the year ending 1990 (Ministry for the Environment, 2016c). An eleven per cent reduction, below 1990 levels, sets the CO₂ equivalent emissions target, by 2030, at just under fifty-four million tonnes (53,934,000 tonnes). In order to meet this target, based on current CO₂ equivalent emissions, (81.1 million tonnes) New Zealand's total emissions must be reduced by approximately twenty-seven million tonnes (27,166,000 tonnes).

The household usage study results, presented in the previous section, suggest that this target will never be entirely achieved by minimizing the emissions associated with household appliance use and behaviour.

At just over two and a half million tonnes, the total CO₂ equivalent emissions produced in the act of dwelling are well below this targeted emissions reduction value, as shown in figure 7.14. However, the earlier exploration of CO₂ reduction of a solely renewable electricity generation mix (see chapter three, figure 3.17), presents an opportunity to further explore possible reductions, if a renewable only electricity generation mix could be augmented with a change in household behaviour.

This earlier CO₂ study of a solely renewable mix previously identified (see chapter three) that current New Zealand CO₂ emissions could be decreased by five per cent due to the lowered CO₂ emissions associated with electricity generation, without changing household usage. As identified in figure 7.15, this five per cent decrease in total emissions achievable through a renewable electricity grid is approximately fifteen per cent of the targeted emissions reduction goal of twenty-seven million tonnes.

7.4.3 Behavioural change in households: possible reductions

The data analysis of the total energy expenditure in New Zealand households identified two prevalent usage traits which could be significant contributors to heightened CO₂ emissions.

The first, as identified earlier in this chapter, is the ownership and operation of multiple appliances, and the second, is the CO₂ intensity of gas powered appliances in comparison to electric powered appliances. The CO₂ intensity of gas as a fuel source is significantly higher than that of the current eighty per cent renewable electricity mix of New Zealand. However, gas appliances may only have a marginal impact even with bigger emissions values, if these are not used as commonly as the many electric powered appliances found in households. Without a specific measurement of the total usage of gas powered appliances in New Zealand households and their corresponding CO₂ emissions, the significance of gas appliances is unknown. Both the observed appliance numbers and unknown effects of gas powered appliances merit further exploration to understand how CO₂ emissions may be reduced. Hence, *single appliance ownership in a renewable electricity mix* is the first theoretical change explored, followed by a *no gas* appliance scenario. All results of the *single appliance ownership in a renewable electricity mix* are presented in the following section with reductions achieved of each presented to together to show the significance of each individual part working in harmony. These are the proposed behavioural changes explored before any other radical changes in household behaviour are investigated.

a. Theoretical change one: single appliance ownership and a solely renewable electricity mix

The initial investigation into appliance number, earlier in this chapter, explored the total energy expenditure if all appliances used the *unchanged* formula. This is how the study identified that a significantly large number of New Zealand households had multiples of many appliances. The appliances listed in the *proportional* formula (and therefore the proportional impact category) were identified as the appliances that are increasing in number.

The significant difference between the impact analyses raises the question of how significantly could CO₂ emissions be reduced if every household owned and operated only one of every appliance currently in use? Simply decreasing the number of the same appliances presents an opportunity to possibly create significant reductions in CO₂ emissions whilst still using all appliance types currently utilised in a household. Therefore, a behavioural change explored here is the possible reductions that could be achieved if all households only have single appliances augmented further with a solely renewable electricity generation mix as discussed earlier in chapter three. In order to measure this scenario, the *unchanged* formula is used for all

appliances. As identified in chapter four, the calculation method of this formula multiplies operational energy of an appliance only by one, not taking into account a change in operational energy if multiple appliances are present.

The results establish that further reductions are observed when single appliance use is implemented in all households combined with a renewable electricity mix. The average household CO₂ equivalent emissions reduce from approximately one thousand six hundred kilograms a year (1,664 kg) to just over seven hundred kilograms (715 kg).

As shown in figure 7.16, the total CO₂ emissions, calculated in the act of dwelling (behaviour or the choices made in the household) for all of New Zealand, decrease from just under two and a half million tonnes (2,578,494 tonnes) to approximately one million tonnes per annum (1,107,975 tonnes).

Figure 7.16 suggests that a simple change in the increased number of the same appliances own can have a relatively large effect on the emissions associated with household behaviour, if this household change is adopted with a renewable electricity mix. This is substantiated by figure 7.17, which identifies that a reduction of over five and a half million tonnes in New Zealand total CO₂ equivalent emissions can be achieved.

Figure 7.17: Estimated NZ total CO₂ equivalent emissions reductions considering both a renewable electricity mix and a single appliance ownership design. The Kyoto Protocol targeted emissions level is represented by the green dashed line. Figures are in million tonnes of CO₂ equivalent emissions (Mt CO₂-e).

Figure 7.17 shows the reductions possible of single appliance use in both the current electricity mix and a solely renewable mix. This shows behaviour can have an immediate reduction. Figure 7.17 identifies that appliance numbers can also reduce overall household CO₂ emissions significantly if policy worked with behaviour, i.e. a renewable mix and single appliance use. A completely renewable electricity mix decreases total national emissions by just under three million tonnes (2,857,935). This reduction is augmented further by only having single appliances using this renewable electricity, approximately decreasing it another 1.5 million tonnes (1,470,519).

However, a policy change in the electricity grid and a behavioural change in appliance ownership achieves minimal reductions in comparison to the Kyoto protocol targets agreed upon. In spite of the fact that the proposed Kyoto protocol target is not reached, this change is a relatively easy change to adopt as the observed CO₂ emissions reduction is achieved without foregoing any appliance use or changes in house size. This is one of the most appealing aspects of this change.

b. Theoretical change two: no gas appliances

During the LCA analysis and calculations, considerable difference in the CO₂ intensity of electric powered appliances in comparison to gas (and petrol) powered appliances was observed. The fundamental difference in gas powered and electricity powered appliances is that, for every kilowatt-hour consumed by an appliance, gas appliances in New Zealand have a CO₂ intensity that is between four and thirteen times more CO₂ intensive than appliances powered by electricity (Rule, Worth and Boyle 2009, pp 6406-6412). This is, in part, due to the relatively renewably sourced electricity generation methods employed in the creation of New Zealand electricity, as discussed in chapter three.

Based on current data there is no indication, other than the much bigger CO₂ intensity of gas as a fuel source, that gas is responsible for significantly higher emissions in households when compared to electrically powered appliances. In addition, gas appliances make up a relatively small majority of appliance types in households (predominantly limited to heating appliances and cooking appliances).

It is therefore, an inaccurate assumption to make, without conducting a detailed LCA on all gas-only appliances for each of the case study households to determine the overall use of gas powered appliances in comparison to electrical appliances. For that reason, the second investigation into possible CO₂ reductions explores how total emissions could be reduced if all gas appliances in households are replaced with electric powered counterparts. The principle limitation here is the appliance replacement selection. For most varying appliance types nominal average figures of electrical counterparts are selected to provide an average representation of this theoretical change.

The average household CO₂ equivalent emissions observed when all gas appliances are replaced showed a similar reduction to what is observed in the appliance number and renewable electricity only change, explored earlier. The average CO₂ equivalent emissions reduce to just over five hundred kilograms (510 kg) for each household. As shown in figure 7.18, with no change to the current electricity grid and replacing all gas appliances with electric alternatives, the total CO₂ emissions, calculated in the act of dwelling (behaviour or the choices made in the household) for all of New Zealand, decrease from just under two and a half million tonnes (2,578,494 tonnes) to approximately 1.8 million tonnes per annum (1,788,435 tonnes).

Therefore, CO₂ emissions associated with household appliance use are again significantly reduced, simply by swapping out all gas appliances. The household emissions reduction shown in figure 7.18 identifies that gas appliances have a relatively smaller CO₂ impact than the increased operation resulting from multiple appliances.

This is reflected in the total New Zealand emissions reduction data plot, shown in figure 7.19, which is not as low as what was achieved by incorporating a solely renewable electricity mix and single appliances in each household.

Even though the household emissions reduction achieved by having no gas appliances is not significantly lower than the reductions achieved by only having single appliance ownership, total CO₂ emissions in New Zealand do not decrease for the second theoretical change as much as it did in the first. This is because, while the household impact is relatively similar for a no gas appliance scenario, a solely renewable electricity mix goes beyond household operation. Electricity generation in New Zealand provides power to all sectors, and is therefore not solely limited to the residential sector. The amount of electricity used in New Zealand homes is much lower than all the electricity created in New Zealand. Therefore, the emissions reduction of a solely renewable electricity mix decreases total emissions much more than what may potentially be achieved by only having no gas appliances in households.

However, one of the biggest advantages of the no gas appliance scenario is that this is a change that can be implemented immediately. Replacing all gas appliances requires no extra technology, changes to the electricity generation grid, creation of more renewable power generation plants or a long timeframe. The side by side comparison, shown in figure 7.20, shows the comparison of both the total New Zealand emissions and also the household emissions when theoretical changes one and two are implemented. Figure 7.20 identifies that gas delivers greater reductions at the household scale but smaller reductions at the national scale because a renewable grid affects all sectors, not just housing.

At the household scale, the no gas appliance scenario has an emission reduction that is a little less than the appliance number and renewable mix scenario. However, when total reductions of both scenarios are compared, the total New Zealand emissions reductions in each case are significantly different, with the appliance number and renewable electricity mix scenario achieving a slightly bigger reduction at the national scale.

c. Theoretical Hybrid change: single appliance ownership with a solely renewable electricity mix and no gas appliances.

Both theoretical changes explored have potential shortcomings and advantages. The biggest advantage of both is that these changes can be implemented without sacrificing any appliance functions or convenience the varying appliance types present. While the no gas scenario is more immediate, the renewable and single appliance scenario has greater reductions that go beyond the household scale.

The relative ease with which both of these changes can be implemented poses the question, how significant could the reduction in household, and New Zealand total emissions, be if a hybrid change of both of these behavioural changes is implemented? In order to address this question a hybrid change is explored that conducts a CO₂ study that incorporates a renewable electricity generation mix, single appliance ownership and also no gas appliances for all households.

This change produced the lowest CO₂ equivalent emissions observed in any of the theoretical changes explored to this point. CO₂ equivalent emissions of household behaviour are reduced from approximately 1,664 kilograms a year to just over two hundred kilograms (204 kg) per household.

As shown in figure 7.21, the total CO₂ emissions, observed in the act of dwelling (behaviour or the choices made in the household) for all of New Zealand, decreases significantly, total household emissions equating to just over three hundred thousand kilograms (316,736 kg). Just over a tenth of what household behavioural emissions are currently.

Figure 7.21 shows that the hybrid change, that addresses all three of the observed trends in appliance operation, has the potential to reduce emissions associated with household behaviour very effectively. This is substantiated by figure 7.22, which identifies that a total reduction of over six million tonnes of CO₂ equivalent emissions can be reached.

Figure 7.22 addresses one of the main research questions posed at the beginning of this thesis. Behavioural changes in the household have the potential to significantly change gross CO₂

equivalent emissions of the existing housing stock in New Zealand. In spite of the fact that the proposed Kyoto Protocol target is not reached, the proposed household behavioural changes explored combined with the implementation of a renewable electricity mix have the potential to reduce total CO₂ equivalent emissions by over six million tonnes. This is approximately twenty-four per cent of the twenty-seven million tonne targeted reduction figure established earlier. The theoretical reduction potential, presented here, is achieved without sacrificing any use of appliance types or changes in the various house sizes currently observed in the housing stock studied.

7.5 The importance of “Hidden emissions”

Earlier in this thesis, chapters three and four theorized the possible existence of *hidden emissions*. This was, in part, due to the observations made of the current methods employed in the ecological accounting between manufacturing and consumer nations. Chapter three established that goods-producing industries (mostly the manufacturing industries) and primary industries have been in decline since the early 1970s, (see chapter three).

Hence, today New Zealand is not considered a manufacturing nation, instead, due to the nation’s heavy reliance on manufactured goods from countries like China, New Zealand is predominantly considered a consumer nation, that creates a demand for products manufactured elsewhere.

The theory of *hidden emissions* posits that due to the manner in which current ecological accounting measures a country’s emissions, a portion of the CO₂ equivalent emissions measured as part of a manufacturing nation actually belongs to the consumer nation. This theory suggests that consumer nations are responsible for the manufacture of goods and use of raw materials due to the demand they create for said goods and raw materials.

Therefore, consumer nations like New Zealand may actually have a greater CO₂ emissions figure than what is reported, which currently does not include the *hidden emissions* associated with manufacturing. These *hidden emissions* come from the embodied energy of products such as appliances that are manufactured in places like China, Germany and even America, countries that currently account for emissions resulting from the manufacture of products used in countries like New Zealand. (IPCC, 2016).

To account for these *hidden emissions*, this part of the chapter compares the results of the LCA findings that specifically establish a CO₂ figure associated with the embodied energy of household appliances with the CO₂ emissions produced by the operation of these appliances.

As identified in chapter four, the CO₂ figures used for the embodied energy calculations are based on CO₂ coefficients from the ICE database, The CO₂ factor of a relatively high carbon electricity mix is also used in these embodied energy calculations. Based on the case study households examined, the operational energy CO₂ figures of current use, and the possible reduction scenarios are compared to the embodied energy CO₂ figures, to understand the importance of said *hidden emissions*; how important these may be based on current use or how important *hidden emissions* may become if reduction scenarios are implemented.

Figure 7.23 identifies the total impact of both the operational energy and the embodied energy of appliance ownership and operation in the case study households examined.

The findings of this LCA study suggest that the CO₂ equivalent emissions of household appliance operation is the bigger contributing factor in the total CO₂ emissions associated with the choices made by households in the ownership and operation of appliances. Although the embodied energy is responsible for sixteen per cent of the total impact, these *hidden emissions*

are a small fraction in comparison to the CO₂ produced in the operation of these appliances, even assuming that the manufacturing takes place in countries with relatively high-carbon electricity and the operation is in New Zealand with its low-carbon grid. These findings are analogous with the theoretical views of Mohammed et al., (2013, p. 213); and; Shoubi et al (in Ain Shams Engineering Journal, 2015, p. 41); who discuss the system boundaries of embodied energy and operational energy, established by Ramesh et al. (2010, p. 1593). See chapter one.

Figure 7.24 depicts the embodied energy and operational energy comparison of the first theoretical change explored earlier in this chapter. At first glance there is a significant reduction in the total CO₂ equivalent emissions of all the case studies examined.

The renewable electricity grid coupled with operation of only one appliance of the multiple appliances identified, decreases emissions associated with appliance operation by 373,823kg, going from 655,483kg to 281,660kg.

However, relative to the embodied energy CO₂, the operational energy is still the larger impact on the environment and is responsible for seventy per cent of total CO₂ emissions. The *hidden emissions* in this scenario are proportionally greater, however, these are still a small fraction

compared to emissions associated with operation. The second theoretical change of having no gas appliances and using electric alternatives has a similar result. Figure 7.24 suggests that the total CO₂ equivalent emissions do have a significant reduction in operational CO₂ emission, decreasing by 200,842kg going from 655,483kg to 454,641kg. However, this reduction is not as big as the first theoretical change explored.

While the outcome is similar to the first change, the significant reductions do make a valuable reduction in the total CO₂ emissions count of the case studies examined. However, the *hidden emissions* are still a small fraction of the operational energy emissions measured.

Conversely, the hybrid change suggests an entirely different relationship between the embodied energy and operational energy emissions. As shown in figure 7.26 the largest emissions reduction scenario is achieved by implementing the hybrid theoretical change. If all of the households examined were to implement single appliance operation, running off of a renewable electricity grid and also replace all gas appliances with electric alternatives, the total CO₂ equivalent emissions figure is significantly reduced.

As shown in figure 7.26, the CO₂ equivalent emissions associated with operation is a fraction of what it is based on current use (figure 7.23). Furthermore, the hidden emissions are now responsible for sixty per cent of the total CO₂ emission figure in the household examined. Earlier in this thesis it was theorized that the implication of appliance use and behaviour could have a significant effect on the conventional way of conducting an LCA. In response to this the *effect on operation* formulae were developed. The aim of this was to understand if embodied energy may be, or had the potential to become, responsible for a greater impact than the impact associated with operation.

This study found that for many appliances, the effect on operation formulae did indeed establish a more accurate figure for how appliances may operate and are inherently used, however this did not suggest a greater impact for embodied energy when compared to the operational energy. However, the results of this study suggest that such a scenario is possible by implementing the hybrid theoretical change in which all households implement single appliance operation, and also replace all gas appliances with electric alternatives. The effect of these changes is then improved by the implementation of a renewable electricity grid. The findings of this theoretical change lines up with arguments presented by researchers such as Waldron et al. (2013) and

Karimpour et al. (2013), who argue that embodied energy, or in this case *hidden emissions*, are more and more important today as operational energy emissions have the potential to decrease due to efficiency. This is best described by the “Balance equation” argument presented by Waldron et al. presented in chapter four (Waldron et al., 2013, p. 1264).

To understand these results at the national scale, figure 7.27 presents a comparative analysis of the results of the current use figure with all three of the theoretical change figures calculated for all households in New Zealand. Figure 7.27 presents the implications such changes may have and more importantly how these changes can take effect. Inherently there will always be an extent to which policy can dictate human choice and behaviour, however, figure 7.27 suggests that an immediate CO₂ emissions reduction is possible if all gas powered appliances are replaced. This fundamentally comes down to human choice. The only other course of action would rely on governing policies to adopt a change for the better. As shown in figure 7.27, the next biggest reduction relies on policy. These steps together achieve a reduction so significant, that the scale of impact has to be revised even in its graphing, as shown in the difference between figures 7.27 and 7.28.

To this end, figure 7.28 shows only the operational energy emissions figure if the hybrid change is adopted. This is plotted next to the hidden emissions figure not currently included in New Zealand's total CO₂ figure.

The data presented in figure 7.28, is important for two major reasons. The first is, that the hybrid change requires no sacrifice of any appliances or demand on raw materials used in the embodied energy figure. All of the changes explored in this thesis proffer a future in which current usage remains the same without having to surrender any luxuries.

Essentially the changes explored here simply attempt to utilise obvious alternative energy sources and appliance types to preserve current unsustainable practices. This is an unrealistic approach to mitigating excessive emissions as discussed by Jevons (chapter three). The second reason behind the importance of figure 7.28 is it specifically highlights where the biggest problem lies.

Figure 7.28: “Hidden emissions” vs hybrid change emissions.

The most significant importance of this thesis are the unknown variables of human behaviour, *in the act of dwelling*, this study has identified. In determining these, the analysis of how to measure behaviour has established an inherent link between ownership and operation.

Therefore, it is plausible to conclude that more significant reductions can be achieved if the embodied energy figure in 7.28 is decreased.

While this figure is the result of international manufacturing practices, this manufacturing market is fundamentally governed by New Zealand demand. Due to the inherent link between ownership and operation, any decline achieved in this demand for manufactured goods will likely reduce operational energy emissions further. However, this will likely require real sacrifice.

7.6 Summary of research outcomes

The main research outcomes presented in this chapter identify the significance of appliance number; the fundamentally significant appliance impact in comparison to house impact for all the case studies examined; and finally, the CO₂ emissions associated with appliance ownership and operation for these case studies, later providing national estimates for all residential households in New Zealand.

The results of the initial investigation into the significance of appliance number established that the majority of case studies examined, all had a substantial increase in the total ecological footprint of the energy expenditure when the proportional formula was applied to all households. This is significant as it revealed that all of the households with a noteworthy increase in energy expenditure had multiples of the same appliance.

This investigation into the significance of appliance number established that multiple appliances were present in most case studies with the only exception being a small number of compact house sizes. In order to ascertain if house size effected the behavioural trait of owning multiples of the same appliances, figure 7.5 presented the impact variation between the two formulae applied against the increasing house areas. These initial results suggested there was no discernible relationship house size had on ownership of multiples of the same appliance.

The second part of this chapter presented the results of the actual ecological footprint analysis of measured appliance ownership and operation. Using the *effect on operation* formulae and impact categories, the ecological footprint of the energy expenditure, measured in megajoules, of each household's appliance use and operation, was presented.

This data identified that for over eighty-four per cent of the case study households examined, the ecological footprint of the appliances (the operation of these during the fifty year life of the house) is equal to or greater than fifteen per cent of the impact of the house itself.

This data also identified that approximately forty per cent of all households examined had an appliance impact equal to or greater than twenty-five per cent the impact of the house. These two results establish that appliance use and household behaviour is significant in regard to the total impact of a household.

This investigation also highlighted a significant behavioural minority. A group of households that were not the biggest houses in the study pool, but had an appliance impact that was more than two times the impact of the house itself. While this larger appliance impact may be expected, due to the relatively compact size of the houses in question, the quintessential behaviour observed here was that all of these compact houses, while having larger appliance impact, had no multiples of the same appliances.

The third part of this chapter identified the results of the study of the total CO₂ equivalent emissions associated with appliance operation. Established using the total number of case studies examined, this section posits that the nationwide CO₂ emissions figure, calculated based on the total number of households in the New Zealand housing stock, equates to approximately two and a half million tonnes per annum.

This total emissions figure of behaviour in the *act of dwelling* was compared to the total CO₂ equivalent emissions of New Zealand to identify how important household behaviour is, considering total emissions from every sector. The results of this study identify that household behaviour is responsible for just over three per cent of all national CO₂ equivalent emissions produced in a year.

The final part of this chapter investigated the total CO₂ emission reductions possible by implementing behavioural changes in all households examined. The reduction techniques explored in the possible CO₂ reductions study were:

1. single appliance households and a renewable electricity mix;
2. no gas appliance households (electricity powered alternatives);
3. a renewable electricity grid

4. single appliance households with a renewable electricity mix and no gas appliance households.

There are many other potential reduction scenarios that may be explored, these are introduced in the further research section in the following chapter. However, all three changes explored in this study show that significant reductions could be achieved by implementing relatively simple changes. These simple changes may however have some potential implications, i.e. a need for new infrastructure for a solely renewable grid (this is also discussed in the following chapter in the implications section). But many of these changes are predominantly policy driven or governed by personal human choice.

The results of the initial investigation identified that the majority of households observed had multiples of the same appliances. Based on this initial investigation of appliance number, the implementation of a completely renewable electricity mix, in tandem with single appliance ownership (as discussed earlier in chapter three), was investigated, this showed that significant reductions were possible with a minor change in the ownership of multiple appliance numbers. The results of the second and third (hybrid) change identified that gas is a major CO₂ intensive power source.

Although it is only used for a relatively small number of appliance types, the CO₂ intensity of this fuel source means the total CO₂ equivalent emissions produced by gas makes up a significant portion of all emissions produced by household appliance operation.

However, the most significant emission reductions can be achieved by replacing all gas appliances with electric alternatives and not having multiples of the proportional category appliances (which many households in New Zealand currently own), whilst using a completely renewable electricity mix, as shown in the CO₂ metres presented in figure 7.29.

The CO₂ metres, presented in figure 7.29, encapsulate the CO₂ investigation and the investigation results. The metres encompass information from chapter three and the various results identified in this chapter.

These metres incorporate three coloured zones on the dials which are designated by the Kyoto Protocol targets; what can be achieved with a completely renewable electricity mix; and finally the current CO₂ equivalent emissions figure. These are consistent for all four metres.

- The threshold between the blue and the red zone identifies what can be achieved if New Zealand electricity was completely renewable as identified in chapter three (figure 3.17).
- The threshold between the green and the blue zone identifies the current Kyoto protocol target, which is eleven per cent less than 1990 CO₂ emissions, as discussed earlier in this chapter.

Figure 7.29 shows the current CO₂ equivalent emissions compared to the possible reductions that can be achieved, which were presented earlier in this chapter. This study shows that although the Kyoto protocol targets are not met, a simple change in household behaviour and national policy shifts the needle on the CO₂ meters significantly, achieving twenty-four per cent of the reduction target.

These simple changes in household behaviour and national policy represent the most viable option for reducing the total emissions in New Zealand without sacrificing any of the convenient appliances each household currently owns. This also substantiates the thesis hypothesis posited at the beginning of this research. Household behaviour, together with national policy changes, have the potential to achieve significant reductions in CO₂ equivalent emissions in New Zealand. Doing so highlights the fundamental importance of *hidden emissions* and the need to minimise these further. These potential reductions resulting from household behaviour and policy changes are discussed in greater detail in the following chapter.

Chapter Eight

Conclusions, Implications & Further Research

8.1 The impact of behaviour

This research raises a number of questions concerning public policy and household behaviour. Among the most obvious questions raised is the need to understand the impact of behaviour and the viability of the potential mitigating factors identified in this research.

This chapter identifies the key outcomes of this doctoral thesis and the conclusions drawn from these. Implications of the findings reported in the results are discussed and the limitations are identified. The last part of this chapter concludes with several avenues for further research and the lessons learnt over the four years it has taken to complete this study.

8.1.1 Aims

This research set out to understand how behaviour within a dwelling impacts on the total environmental impact of a New Zealand house. To do this, one of the first objectives of this research was to understand the current criteria by which the total impact of a New Zealand house is assessed. This investigation established that there are more than 140 alternative and modified definitions of the term sustainable development, which has been used by various

criteria and labelling systems to assess household impact. The fundamental connection observed between all impact assessment methods was a lack of consideration for behaviour.

The review of literature here found that while there is a great deal of literature that explores a very definite link between human behaviour and resources use, there is no existing framework for understanding how behaviour quantifiably affects the total impact. This was the significant gap of knowledge identified in the early stages of this thesis.

With a goal of establishing and testing such a framework the research question posed in this thesis was, to what extent does household behaviour, the act of dwelling, affect the life cycle impact of a New Zealand house in its totality?

It was hypothesized that behaviour plays a significant role in how sustainably people live. This cannot simply be measured in terms of technologies employed as behaviour has the potential to affect both the embodied energy within a dwelling and also the operating energy based on individual decisions made by the occupants.

8.1.2 Process

To address the thesis question an in-depth analysis of consumer behaviour was conducted over chapters two and three. Looking first at the global scale and then at the national scale, a clear interdependent relationship was recognized between New Zealand, a consumer nation with a predominantly service based economy, and manufacturing nations such as China and America. The nature of this interdependent relationship means that most of the manufactured goods used in New Zealand are not originally from New Zealand and thus their embodied energy count is not included in the country's emissions figure. This led to the theory of *hidden emissions* which made identifying the impact associated with embodied energy all the more significant.

To focus the scope of this study, trends in rising emissions were examined to establish where human behaviour may best be investigated. The findings of this study showed that the most significant increases in recent emissions came from the energy sector. To understand the role New Zealand households may have on these increasing emissions, a question of appliance impact was raised and subsequently became the primary focus in the process for establishing the impact of behaviour in a New Zealand house. Unlike other behaviourally-related aspects of

living, such as furnishings and fit-out, which have embodied energy, appliances also consume energy in operation and are therefore likely to have a greater life-cycle impact.

By means of an in-depth life cycle assessment, the 394 HEEP households were examined to identify the ownership of the various household appliances that use finite raw materials in both operation and manufacture. In order to appropriately measure embodied energy and operational energy, a series of formulae were developed that specifically addressed the likely effect that ownership of multiple appliances had on the operation of appliances. Dubbed the *effect on operation* formulae, these were tested to ascertain the significance of appliance number. This determined these formulae produced more accurate results based on how various appliances would potentially function, if appliance number increased.

8.1.3 Outcomes

This research represents a preliminary examination of the impact of consumer behaviour on the total energy of a New Zealand house. From this investigation, a number of conclusions are drawn:

- The most common appliances that households have multiples of are appliances that proportionally increase operational energy, according to the number of appliances.
- Life stage and house size have no significant link to appliance ownership and usage.
- Behaviour is responsible for only three per cent of national emissions.
- The in-depth measurement of hidden emissions in the tear down study reveals embodied energy has the potential to be greater than operational energy.

Here these conclusions are discussed in detail. The CO₂ analysis of household emissions identified that household behaviour (which does not include emissions associated with appliance manufacture - embodied energy) is responsible for only three per cent of all national CO₂ equivalent emissions. This analysis also identified that simple changes in behaviour have the potential to significantly reduce the nationally-related part of these household behaviour emissions. The largest part of this is cutting household behaviour emissions by half by eliminating the use of gas appliances. The study in chapter three identifies that instead of changing household behaviour, which is responsible for only three per cent of total national

emissions, policy changes such as a completely renewable electricity mix, have the greater reduction potential, achieving twice the reduction that can be achieved through behaviour alone.

All three of the reduction scenarios, explored in chapter seven, support this finding in chapter three, suggesting that a policy change to achieve a completely renewable mix for the generation of electricity has a greater reduction potential than household behaviour alone.

However, chapter seven also suggests that the greatest potential reductions can be achieved by implementing both the policy change to include fully renewable electricity generation and household behavioural changes in the form of having no gas appliances as well as single appliance ownership.

This is potentially the most significant outcome of this thesis. That is policy and behavioural changes, together, have the potential to change the dynamic of embodied energy and operating energy as it is observed today, making the operating energy of household appliance use much smaller than their embodied energy.

This highlights the importance of hidden emissions, identified earlier in chapter three, section 3.7. With embodied energy increasing, hidden emissions bring to light a crucial need to monitor/regulate and account for embodied energy emissions in the countries that introduce these emissions from manufacturing nations. As identified in this thesis, New Zealand is an example that demonstrates this. New Zealand is responsible for emissions of manufactured goods because it is a service led economy that has limited national manufacturing emissions, hence these are imported. This suggests significant implications on how international/global emissions are currently accounted for.

In this research, New Zealand's hidden emissions have been established by vigorously measuring the material quantities of various household appliances in a tear down study (see chapter five). While these hidden emissions are relatively small when compared to the current operational emissions, that are included in the national emissions figure, the comparison of these hidden emissions to the reduction scenarios, examined in this research, established an unprecedented outcome. A series of simple changes in human choice and public policy have the potential to reduce operational energy emissions so significantly that the hidden emissions associated with embodied energy could have the potential to represent sixty per cent of all emissions related to household behaviour. These findings highlight the importance of the

balance equation and the claims made by researchers such as Fay et al., 2000; J.B. Guinée, 2002; Wu et al., 2010, who argue that embodied energy is potentially significant, and merits further investigation, as discussed in chapter four.

8.2 Implications

As a result of these findings, there are a series of implications that this study has revealed. These are:

1. Lighting changes not included in the survey
2. Reduction scenarios – impact on house design
3. Reduction scenarios – viability considering infrastructure

This research attempts to propose viable solutions that can facilitate a change towards a better, more sustainable, future. To that end, the following sections detail the four implications of reduction scenarios presented in chapter seven.

8.2.1 Lighting LEDs?

The ten-year HEEP study recorded an extensive volume of data, which included everything from characteristics of the household to a walk through audit, (see appendix A for Household energy use survey). However, there are some implications in house design for which this study, given that it was conducted some years ago, has not recorded data. Household lighting, since the completion of the HEEP study, has seen varying advancements in technology, specifically the use of LED lighting.

LED lighting in the residential sector was not common during the HEEP study, in fact New Zealand's leading manufacturer of LED lighting (Switch Lighting 2017) was only incorporated into the Companies' Office register in 2009 (Companies Office, 2017). LED lights were not included in the LCI data set created in this thesis (see appendix C). However, in order to speculate on possible operational energy reductions, this is an area for further research (see section 8.3.3 that discusses the integration of newer technologies).

Single appliance use: lighting design implications

Current appliance use
(House Lighting design)

Single appliance use
(House Lighting design)

Figure 8.1: Household single appliance use: Lighting design implication.

8.2.2 House design

Implementing single appliance use and no gas appliances would likely have far reaching implications across New Zealand. These will include accessibility to electricity and changes to the infrastructure as identified in section 8.2.4. However, this will also have implications for house design, especially given the definition of an appliance as outlined in this thesis.

Implications of the reduction methods identified in this thesis will include things like the reimagining of a household lighting design to incorporate a single appliance scenario; one light in a space instead of six. It is the opinion of this candidate that most residential spaces, if designed properly, can minimise lighting (and all appliance use in general) to a much smaller number, if not single appliances in many cases. User preference and inadequate lighting are things a well-designed space, with appropriate (purpose-built) luminaires, can tackle. This is certainly true for living rooms, bathrooms, toilets and, arguably, bedrooms. The light layout, in figure 8.1 is an example of New Zealand Building Code requirements for residential lighting, all of which are met with a single fitting according to current standards written in accordance with section 22 of the Building Act 2004 (NZBC document G8. 2017, pp. 2, 14).

However, this is an area worth further study which is well outside of the scope of this thesis. This is, in fact, currently (August 2017) the topic of another Ph.D. Student at the Victoria University of Wellington, School of Architecture, research which is due to be completed in coming months. Single appliance use will also have implications on storage space; less appliance number can decrease the need for extra storage space, and food storage. Only having a single refrigerator will likely decrease the amount of food stored in a New Zealand house.

8.2.3 Infrastructure change

Changing all households across New Zealand to no gas appliances will involve infrastructure changes to the electricity grid (accessibility to electricity may need to be improved in some rural locations if bottled gas is no longer available).

Implementing a solely renewable electricity grid will likely be much more complicated than simply bolstering energy generation of all current renewable systems. This is an area that merits further research and has implications for the viability of some of the reduction scenarios presented in this thesis.

As shown in figure 8.2, the current electricity grid relies on generation sources across New Zealand. However, meeting generation requirements and accessibility to the grid may be more practicable than it seems.

Figure 8.2: Energy sources in New Zealand. (Ministry of Economic Development, 2012, p 6).

Figure 8.3: Tiwai Point aluminium smelter (NZAS, 2017).

The Tiwai Point aluminium smelter (figure 8.3) is New Zealand's only aluminium smelter, it is co-owned by Japan's Sumitomo Chemical Company (NZAS, 2017). The aluminium smelter consumes approximately thirteen per cent of all electricity generated in New Zealand annually (NBR 2017). This is significant as there have been multiple reports of the smelter's closure since 2016. (Stuff, 2017; NBR, 2017; Herald, 2017). The closure of this smelter would decrease the electricity generation load on the New Zealand grid significantly and make a solely renewable electricity grid even more viable;

"Tiwai remains an uncertainty for the industry," the note says, with options to cancel existing electricity contracts triggering in April and January next year ahead of possible closure in early 2018 or a staged reduction in output. "Surprisingly perhaps, we think the risk of an early 2018 exit remains low despite bombed out aluminium prices." The smelter uses 13% of all the electricity generated in New Zealand. Its closure would create potential for over-supply and the early closure of more fossil fuel-fired power stations than has already been announced. (NBR, 2017).

The path to a solely renewable electricity grid is an area that merits further research as discussed in section 8.4.3.

8.3 Limitations

It should be noted that this research is not without limitations. First, this thesis only looked at the residential sector based on the households examined in the ten-year HEEP study. While this study is extensive and representative, it is still limited due to the type of residential housing that is omitted. Second, some the appliances used for the tear down studies to establish the LCIs were unavoidably up to twenty to thirty years old. They may not represent current

technology for a small number of categories of appliances. Third, some newer technologies are not considered in this study. Newer appliances like iPhones or tablet PCs have not been examined in this study. Newer technology may have skewed some of the results for appliances in the entertainment category. Appliances such as multifunction gaming consoles or televisions with built-in decoders are variables that could not be included in this analysis. Furthermore, this study is a New Zealand only study and it does not consider reductions in other sectors outside the residential sector or include the impact of transportation that is associated with imported goods. These limitations are discussed in detail in the following sections.

8.3.1 Housing not considered

The usage study is based on HEEP data that looked at 394 separate houses and not apartments or inner-city dwellings. As shown in figure 8.4, the end of the data collection period established a 100 per cent coverage of New Zealand. As such the impact study conducted in this thesis can be considered a relatively representative analysis. However, further study could potentially go beyond the data collected in the HEEP study to examine the impact of behaviour in inner-city dwellings and apartments.

Status	Report Year	Regions covered in report analyses	House count	Number of houses used for report	Percentage coverage of NZ
Pilot	1	Wanganui, Christchurch	18	10 Wanganui, 8 Christchurch	Not a random, representative sample
Pilot	2	Wanganui, Christchurch	37	29 Wanganui, 8 Christchurch	
Pilot	3	Wanganui, Wellington	40	29 Wanganui, 11 Wellington non-random	
Pilot	4	Wanganui, Wellington	81	As Year 3 plus 41 random Wellington. Varied by analysis.	
Full	5	Wanganui, Wellington, Hamilton	109	As Year 4 plus 17 random Hamilton, 11 non-random Hamilton. Varied by analysis.	13% for analyses based on random sample. Still much non-representative analysis.
Full	6	Auckland, Hamilton, Wellington	160	As Year 5 plus 50 random Auckland	37% for analyses based on random sample. Some non-representative analysis
Full	7	Auckland, Hamilton, Wellington, Christchurch + other areas by questionnaire only	260	As Year 6 plus 47 random Auckland, 36 random houses Christchurch, 10 random houses Waikanae.	47% for analyses of temperatures and energy based on random sample. About 75% for analysis based on HEEP survey. Most analysis are representative, though the coverage varies
Full	8	As above plus half of the 'rest of NZ' sample	~300	As Year 7 plus half of the 'rest of NZ' sample	75% for analyses of temperatures and energy based on random sample. 100% for analyses based on HEEP survey. Most analysis will be representative, though the coverage will vary
Full	9	Complete	~400	Complete	100% monitoring and survey

Figure 8.4: Coverage of HEEP study. (BRANZ, 2003, p 3).

This is a potentially valuable future study as apartments and inner-city housing are on the rise in many New Zealand cities. As identified by Statistics New Zealand;

In the 10 years between the 1996 and 2006 Censuses, the number of people living in inner city apartments in Auckland, Wellington, and Christchurch almost quadrupled, from 4,974 to 19,020. Over two-thirds (70 percent) of this growth occurred in Auckland where the number of inner city apartment dwellers more than quadrupled, from 2,805 to 13,311. In Wellington, the number more than tripled, from 1,410 to 4,743. (Statistics New Zealand 2017).

8.3.2 Old appliances in the tear down study

Another major limitation in this study is the age of some of the appliances used in the tear down study. As a result of scarce data accessibility (see chapter four), a teardown study of all appliances was conducted. The appliances for this study were inevitably, second-hand appliances or appliances at the end of their lives. Hence, they are between seven and thirty years old. This essentially means that some of the LCI data collated in the teardown study may not incorporate the newest manufacturing processes.

To create a representative LCI data set a comparison of the tear down data with open source repositories has been conducted in this thesis. This means that the final LCI figures used in this thesis take account of older appliance figures in many instances (see chapter five). However, there are limitations based on the assumptions made in this data collation process, as identified in chapter five. Without conducting an LCA on new appliances, which was implausible in this thesis, up to date manufacturing processes are much more difficult to measure in a tear down study.

8.3.3 New technology

As mentioned earlier in section 8.2.1, the integration of newer technologies not included in the HEEP study is an area that merits further research. There are many implications not considered in this study in terms of how users may potentially be using devices like iPhones or tablet PCs that may be changing the effects of operation in these appliance categories. Lighting is again an area that has seen huge advances in efficiency due to the implementation of LED lighting in the household as discussed earlier.

8.3.4 Transportation

Finally, this research did not look at the embodied energy of transport, such as the transport of timber for burning in the wood stove. The embodied energy of wood fuel was determined based on research conducted by Andrew Alcorn which looked purely at the process of harvesting and processing newly sourced timber in New Zealand. This merits further study as there are many sources that could be tapped for wood fuel in this country.

Transportation has also been omitted in the embodied energy figures calculated for all manufactured goods. This is an area that will likely add embodied energy to the hidden emissions that have already been identified as a potentially large impact area in future emissions.

8.4 Further research

This thesis studies the theoretical possibilities for reducing impact as a result of household behaviour. There are plenty of practical steps further research can take to apply and improve the results of this study. Future work includes:

- a specific-survey analysis of appliances and ownership
- detailed survey-specific approach to better understand the *Unknown Increase* category;
- looking at electricity consumption trends and generation capabilities in detail to better understand the path to a 100 per cent renewable mix;
- Looking at hidden emissions testing in nations with service based and manufacturing led economies;
- External verification of the adopted methodology.

These areas of further research, link with the implications already presented in section 8.2 and are discussed in detail in the following sections.

8.4.1 Specific- survey analysis

Pursuant to the terms and conditions of data use with BRANZ (see appendix A), none of the unit data used in the calculations of the LCA in this thesis are reported or available in the public forum. As a result, there is still a level of transparency this thesis cannot adhere to. Lack of transparency and data availability is a major problem in any LCA.

As discussed in chapter four. One of the major obstacles overcome during this thesis was the development of a detailed materials quantity data set. Hence, the data set created in this thesis is the first complete data set of this kind that will be available in the public forum. It is anticipated that making a data set of this magnitude accessible will allow further research to make use of manufacturing information and also add to it as manufacturing processes change and evolve.

However, as identified earlier in section 8.3, all LCA calculations conducted in this thesis are based on data collected from the ten-year HEEP study. As a result, the unit data used in the calculations cannot be appended in this thesis. Further research or potentially a post-doctoral study could apply the effect on operation formulae and the procedure outlined in chapter four to an independent study.

An examination of household behaviour based on a study-specific survey could potentially enhance the data collected and also make it possible to share all unit data of appliance ownership. The appended “Household energy use questionnaire” could potentially be used for this and further enhance the quality of data collected, to substantiate the outcomes identified in this thesis.

A survey specific analysis has the potential to decrease the number of appliances listed in the *Unknown Increase* category as discussed in the following section.

8.4.2 Unknown increase?

As identified in chapter four, the *Unknown Increase* category applies to appliances for which increased appliance number causes an unknown, often variable, increase in original operational energy.

$$EE + OE_{original\ total} = Total\ Impact$$

$$\left(\sum_{i=1}^{n_{appliance}} EE_i \right) + x(OE_{original\ total}) = Total\ Impact$$

- Equation 4

The fundamental problem with appliances that fall into this category is that the increase in operation has no predictable pattern. Owning another unknown increase appliance would not simply increase energy use proportionally. In these instances, there may be appliances that have a causal relationship with operational energy.

Figure 8.5: The “Effect on Operation” is an “Unknown Increase” as a result of an increase in appliance number as shown in chapter four.

This is an area that merits further research. As discussed earlier in section 8.4.1, a survey specific study has the potential to identify how all appliances are used by simply incorporating unknown appliances in the measurement process. This was well outside the scope of this study and due to time restrictions was not attempted. This is a task best suited for a post-doctoral study.

8.4.3 Path to a 100% Renewable Mix

As discussed in the limitations section, the future CO₂ figure established for the solely renewable mix in this thesis was calculated based on an equal increase in energy generation from the current mix of renewable sources to meet energy generation predictions, this is an area that merits further research. The future electricity requirement figure was based on data trends available from open source information. This is limited to Ministry of Business, Innovation and Employment data that goes far back as 1974. As a result, further research is needed to accurately predict future generation requirements and the effect these may have on the viability of a solely renewable electricity mix in New Zealand.

8.4.4 Hidden emissions testing application in manufacturing nations – Relationship

When considering the independency of New Zealand with the global market there is essentially a clear-cut line between New Zealand; a consumer nation with a service based economy, and manufacturing nations; that are an amalgam of both services based and manufacturing led economies. However, this relationship may not always remain the same. More importantly, there are many countries like Australia and America and China in which manufacturing may have a different impact on the emissions associated with of behaviour. Further research into the effects of varying economic models or even looking at *hidden emissions* in manufacturing nations may potentially reveal some interesting patterns of use.

This study would also have the potential for optimizing current emissions around the globe by understanding *hidden emissions*, i.e. could potentially manufacturing aluminium using renewable energy in New Zealand for worldwide distribution be a less carbon intensive solution to potentially large hidden emissions in manufacturing nations like China?

8.4.5 External verification of the adopted methodology

The external verification or testing of the adopted methodology is a limitation and is an area for further research. In this thesis this was not possible because of the nature of the work. However, a programme of research that tests each *effect on operation* formula, (*Proportional, Unchanged and Unknown Increase* – see chapter four) against surveyed household appliance use and ownership data would substantiate the validity of the methodology established in this work.

8.5 Concluding statement

The impact of behaviour, identified in this thesis, suggests household energy usage based on day-to-day behavioural choices is relatively small when compared to total national emissions. However these emissions can be greatly reduced with minimal sacrifice. National emissions can be further reduced by implementing policy changes and changes in household appliance ownership and use. However, personal human choices made in the New Zealand house have created a world of our own making, in which even with per capita usage of electricity on the decline, the anthropocentric nature of our species is still leading to household choices that do

very little to solve increasing emissions. However, the altruistic nature of humankind may have the potential to create a change by implementing policy and making personal choices that could potentially preserve resources for the sake of posterity.

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Appendix A

BRANZ data terms and conditions/Survey

Enclosed in this appendix is the BRANZ survey that was used to collect the data used in the LCA calculations in this study. The terms and conditions for use of this data are also enclosed.

USE OF BRANZ HEEP DATA

HEEP data is provided for the exclusive use of Nilesh Bakshi for his PhD studies only. No data is to be retained or used for any other work or to be provided to any other party.

HEEP data contains private information. Specific details that immediately identify the dwelling or the householders will not be provided in data extracts. No names or addresses (other than the city or area unit) is to be shared. In using the HEEP data, you agree to maintain the confidentiality of the HEEP participants and will not attempt to establish the identity of any particular household.

Whilst BRANZ has no reason to believe that any information contained in the HEEP data is inaccurate, BRANZ does not warrant the accuracy, adequacy or completeness of such information nor does BRANZ undertake to keep the information updated.

BRANZ does not give any assurances that any information contained in the extracted set of HEEP data will be suitable for your purposes and only general assistance can be provided into the interpretation of the data.

In using the HEEP data you agree that you will not represent any analysis you undertake as being an output of the HEEP research ('the HEEP data says...') but that your work makes use of HEEP data ('my analysis of the HEEP data shows...').

No unit data is to be presented in any output of the research. Any tools or calculators which operate on data is not to make available the individual HEEP unit data. BRANZ is permitted to audit the research outputs to ensure that the research is compliant with this requirement.

BRANZ does not accept responsibility for any loss, damage (including indirect, special or consequential loss or damage), however caused (including through negligence) that you may directly or indirectly suffer in connection with your use of or reliance on the HEEP data provided, including the accuracy or currency of the HEEP data. Any condition, warranty, right or liability which would otherwise be implied is excluded.

	Nilesh Bakshi	For BRANZ
sign
Date	23.06.2015	

HOUSEHOLD ENERGY USE QUESTIONNAIRE:

(version 19) HEEP 2004

Note: Section E is now with the setup sheets

code:	
-------	--

Date Time.....

Address (Street)
..... (Suburb)
..... (Town/City)
Phone (Day).....(Evening)

Name of Interviewee/s

Name for Correspondence (full name + title)

A CHARACTERISTICS OF THE HOUSEHOLD

When the occupant is unable to answer please put don't know (D/K or -9) rather than leaving the answer box empty.

I'd like to start by asking about your household.

A.1 OCCUPANT DETAILS

A.1.1 Could you tell me who is living in this household at present:

person	name (first name ok)	male/female	age
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

If the Occupants change please inform the download person

A.1.2 Which of the following best describes your household ? (card 1)

- 1= one family household
2= one family with others;
3= more than one family/household;
4= non family (eg flatmates)
5 = one person household

A.2 TYPE OF TENURE:

A.2.1 Which of the following best describes the ownership situation of this dwelling? (card 2)

- 1 = occupants own dwelling with mortgage
2= occupants own dwelling without mortgage
3= occupants rent/lease dwelling;
4= other

A.2.2 How many years have you occupied this dwelling?
(less than one = 0)

B ELECTRICITY AND LIVING PATTERN

B.1 OCCUPANCY HOURS

B.1.1 Typically how many adults (ie 15 and over) & children are usually at home (ie not at work, school or elsewhere):

during week day
week night

adults	children

(if no children in house code as -999)

B.1.2 What time do the members of this household usually get up and go to bed during the week?

Put name in the space - start with main interviewee (check back to page 1 question on household membership)

get up
time

bed time

Person 1:		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

B.2 WATER HEATING

B.2.1 *What systems are used to heat water: (Use ONE code for ONE system)*

1= electric cylinder 2= gas cylinder 3= zip heater 4= solid fuel cylinder
 6= elec & solar 7= heat pump (i.e. Quantum) 8 = instant gas 9 = other
 10=Nightrate elec 11=instant electric 15= elec & wetback 16=elec., solar & wetback
 25 =gas & wetback

Note: Ask explicitly about wetback and solar collector!

1	
2	
3	
4	

~~B.2.2 Other means of water heating.....~~

B.2.3 *What is your main means of water heating?* (code system number as above)

B.2.4 *Where is the hot water cylinder located?*

1 = cupboard, within interior of house,
 2 = cupboard, on exterior wall of house,
 3 = unconditioned space ie garage, roof space, or on exterior wall
 -999 = n.a. (no cylinder, instant gas)

B.2.5 *Is the cylinder cupboard used for linen (or any other material) storage?*

1 = yes 2 = no -999 = n.a.

B.2.10 *If electricity - what tariff is water heating on?*

1= standard 2 = Night rate/tariff 3 = mixed tariff -9 = dk -999 = n.a.

B.2.11 *How many baths in this dwelling?*

B.2.12 *How many showers?*

B.2.13 *How many 'shubs'?*

-999 = n.a -9 = don't know

B.2.14 *If so, approximately what is the volume of the 'shub'?*

 m³

B.2.15 *Is the shub used as a bath?*

1 = yes 2 = no -999 = n.a

B.2.16 For each person what are their usual (weekday) bathing habits: (fill in each box with a number, D/K or N/A)

Person (as per prev question)	showers/wk (number or DK)		baths/week	usual time of day 1 = morning 5= morn & eve 2 = afternoon 6=after & eve 3 = evening 7=m & a & e 4 = morn & after	preferred temp 5= very hot 4= hot, 3=warm 2=cool. 1=cold	• if shower - how long (mins)
	1	2				
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
total bath-fills /week ?						

B.2.17 Is your shower/s fitted with a low pressure or low flow shower head ?
1= yes 2 = no -9 =dk

shower 1
shower 2

B.2.18 Do you sometimes run out of hot water ?
1 = yes 2 = no -9 = dk

B.3 MOISTURE SOURCES

B.3.1 Do you have any open fish tanks?
1 = yes 2 = no

B.3.2 How many house plants do you have?
1 = few 2 = lots 3 = none

B.3.3 How many cats live mostly inside?

B.3.4 How many dogs live mostly inside?

B.4 LAUNDRY

B.4.1 Do you have a washing machine? - what sort?
1 = manual 2 = automatic 3 = none

B.4.2 Make of Washing Machine:

B.4.3 Where do the laundry doors open to?

1 = outside 2 = porch 3 = hall 4 = other room in house 5 = other
(multiple answers accepted)

B.4.4 Does your household mainly do its own washing?

(Tick 'no' if you send it out instead or it is done somewhere else.)

1 = yes 2 = no

If do own a washer? (if answer is no then write N/A for B.4.5 to B.4.7)

B.4.5 On average how many loads of washing are done in this household per week?

B.4.6 When in the day is the laundry usually done

Week day (1 = morning 2 = afternoon 3 = evening)
Weekend (1 = morning 2 = afternoon 3 = evening)

B.4.7 Usual type of wash:

1= cold 2 = warm 3 = hot

B.4.8 How is the washing usually dried?

1 = clothes line 2 = drier 3= both 4= other

winter
summer

B.4.9 Do you have a clothes dryer ?

1 = tumble 2 = cabinet type 3 = none

B.4.10 To where does your dryer vent?

1 = outdoors via vent 2 = outdoors via door
3 = into house 4 = into laundry only -999 = N/A

B.4.11 When do you use your dryer? (card 3)

1 = following all washes 2 = whenever weather is doubtful
3 = if in a hurry for necessary items 4 = only as last resort -999 = N/A

Winter
Summer

B.4.12 On average how many hours is the dryer used each week?

-999 = N/A

Winter
Summer

B.4.12.a When do you dry clothes inside – air drying (multiple answers possible)?

1 = following all washes 2 = always in winter
3 = whenever weather is doubtful 4 = only if it's raining
5 = only if clothes are dry already (airing) 6 = other (please describe.....)

B.4.13 Do you have a spa pool / hot tub?

1= yes 2 = no

B.4.14 Do you have a heated swimming pool?

1= yes 2= no

means of heating:.....

B.4.15 Do you have an unheated swimming pool?

1= yes 2= no

B.4.16 If you have a spa and/or a heated swimming pool do you use a thermal pool cover when the spa/pool is not in use?

1= yes 2= no 3= sometimes -999= N/A

B.4.17 If spa pool/tub How many times a week is it used on average?

-999= N/A

B.4.18 What temperature is it maintained at?

-999= N/A

B.4.19 Where is the spa?

1= indoors

2= outdoors

-999= N/A

B.4.20 If heated swimming pool What temperature maintained at?

-999= N/A

B.4.21 Where is the pool?

1= indoors

2= outdoors

-999= N/A

B.5 HOME HEATING

B.5.1 Over which months do you heat your home?

(heating season).....to.....

B.5.2 Which of the heater types listed on card 4 do you use to heat your dwelling?

Permanently Fixed Heaters:

- 1 = electric night store
- 2 = electric panel heaters
- 3 = electric radiators (eg. bar heater with glowing element)
- 4 = electric central heating (multiple rooms – with or without thermostat)
- 5 = under floor heating, electric (under floor or under carpet)
- 6 = in-ceiling/wall
- 10 = wall fan heater
- 16 = air conditioner (used for heating)
- 25 = heat pump
- 7 = enclosed wood or coal burner /pot belly
- 8 = open fire
- 9 = solid or liquid fuel fired central heating
- 17 = reticulated natural gas (flued), non central
- 18 = reticulated natural gas (unflued), non central
- 20 = gas central heating (multiple rooms– with or without thermostat)
- 21 = gas underfloor heating

Portable heaters:

- 12 = portable convection heater (eg. oil column)
- 23 = electric radiator (eg. bar heater with glowing element)
- 24 = fan heater
- 13 = portable kerosene
- 14 = electric blankets: single
- 15 = electric blanket: double
- 19 = LPG
- 22 = dehumidifier (used for heating)

Heater No.	Most used (rank 1, 2...)	Heater type	Usage 1 = used 2 = own but do not use it	kW rating	Hours used per week	No. of rooms heated	Room type 1 = liv, lge, din 2 = bedrooms 3 = service	Heater descr. (eg. oil column, fan heater, etc)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

B.5.3 Of these, which do you use the most to heat the house?

Heater No.

Note: Get kW ratings from appliances, or power measurements, or gas setup sheets

B.5.4 Did you use heating in the last 7 days - if so what type and on what days?

1 = yes

2 = no

B.5.5 Do you have air conditioning?

1 = yes

2 = no

if 'yes' specify type, size, economiser, usage (cooling, dehumid.,)

.....

B.5.6 If yes: Typically how many hours/week would you run it in summer?
(N/A or -999 if not applicable)

B.5.7 Do you have mechanical air transfer ducts?

1 = ceiling

2 = room to room

3 = no

B.5.8 Does your heating achieve comfortable conditions over winter?

1 = sometimes

2 = mostly

3 = always

4 = rarely

B.5.9 If not always - why?.....

B.6 COOKING

B.6.1 What means of cooking do you have? (card 5)

	Number of appliances	tick if used	Main means (in order of importance)	code
1 = electric range (oven + hobs)			most important	
2 = gas range (oven + hobs)			2 nd most imp	
9 = electric oven				
10 = electric hobs				
11 = gas oven				
12 = gas hobs				
3 = wood/coal range,				
4 = microwave,				
5 = electric frying pan,				
6 = bench-top mini oven				
7 = crockpot				
8 = induction cooking				
13 = separate electric grill				
14 = separate gas grill				
15 = rice cooker				
16 = LPG BBQ				
17 = coal/wood BBQ				
18 = electric BBQ				

B.6.2 Does your household usually have home cooked food for the following meals

go through the list (1 = yes 2 = no)

Weekday breakfast

Weekday midday meal

Weekday dinner/ evening meal
 Weekend breakfast
 Weekend midday meal
 Weekend evening meal
 Weekend brunch

B.6.3 *What time in the day (eg 6.30pm) do you have your main cooked meal?*
 (remember am or pm)

--

B.6.4 *How many people are usually here for the main weekday meal?*

--

B.6.5 *Do you use a dish washing machine for washing up?*
 1= yes 2= no

--

B.6.6 *Does anyone in the household do any baking?*
 2 = no,
 if yes: how often? 4= at least once wk 5 = fortnightly 6= monthly 7= less often

--

B.7 **APPLIANCES**

B.7.1 *Does anyone in the household have a hobby which involves using a lot of electricity at home (eg pottery)*
 1=yes 2=no

--

B.7.2 *If yes what*

B.7.3 What other appliances/facilities (as listed on card 6) do you have in your home?

code for frequency of use: (N/A or -999 if not applicable) PUT A LINE THROUGH THE LAST

COLOUMN IF NOTHING IS PLUGGED INTO THE RANGE

1 = constant 2 = daily 3 = more than 1/week 4 = approx 1/wk
5 = approx fortnightly 6 = approx 1/mth 7 = < 1/mth 8 = Never

	number	how often used	How many hours on average per appliance and week? (Otherwise note "total" i.e. for lights)	It is plugged into the range (1 =yes)
3001	iron			
6002	deep freeze (age.....)			
6001	refrigerator (age.....)			
6003	combination fridge/freezer (age.....)			
4302	range hood			
5002	toaster			
5001	electric jug/kettle			
5003	coffee maker			
4301	extractor fan			
5005	food processor			
5004	mixer			
5006	bread maker			
3006	waste master			
3004	vacuum cleaner			
3002	sewing machine			
1003	fluorescent lights - fixed			
1004	- portable			
1001	incandescent lights - fixed			
1002	- portable			
1005	Halogen lights - fixed			
1006	- portable			
1007	Compact Fluorescent - fixed			
1008	- portable			
4003	heated towel rail (rating W)			
4001	heat lamps			
4002	cupboard heaters (rating W)			
4122	dehumidifier			
(4401)				
	Entertainment:			
7001	TV			
7002	Video			
7003	stereo			
7007	home PC /computer game			
7004	separate radio/cassette			
7005	Sky / Saturn decoder			
	Miscellaneous:			
3018	electric lawn mower			
3015	heated fish tank			
3003	electric power tools (i.e. paint stripper)			
3012	weed eater			

B.7.4 Are there any other electrical items in the house that are used frequently? e.g. waterbed

B.7.5 On average, how many hours in the day and the evening is the main TV usually on in this household?

	day (to 5pm)	evening (after 5pm)
weekdays - Monday to Friday		
weekend - Saturday & Sunday		

B.7.6 Do any occupants work from home? i.e have a home office or workshop

1=yes 2 = no,

B.7.6a If Yes, how many hours/week is it used on average?

(N/A or -999 if not applicable)

B.7.7 How often is the fridge re-loaded with food?

2=daily 3=more than once a week 4=about once a week
5=fortnightly 6=monthly 7=less freq. -999=NA

B.7.8 How often is the freezer re-loaded with food?

2=daily 3=more than once a week 4=about once a week
5=fortnightly 6=monthly 7=less freq. -999=NA

B.7.9 Is your fridge built-in or stand alone?

1 = stand alone 2 = built-in. -999=NA

B.7.10 Is your fridge/freezer built-in or stand alone?

1 = stand alone 2 = built-in. -999=NA

B.7.11 Is your freezer built-in or stand alone?

1 = stand alone 2 = built-in -999=NA

B.7.12 What sort of Freezer do you have?

1 = chest freezer 2 = vertical freezer -999=NA

C POWER CONSUMPTION

C.1.1 Who usually pays the power bill in this house?

(if present direct following questions to them)

C.1.2 Without looking, can you tell me approximately, what your bill was last month?

(check whether one or two months covered by bill?)

C.1.3 How many units?

C.1.4 What is your typical monthly power bill?

Electricity	Gas

summer
winter

Ask to see last power bill - fill in details here:

C.1.5 Total bill \$:

C.1.6 Total units

C.1.7 Standard tariff: units

C.1.8 Night rate units

C.1.9 Is the bill detailed above estimated ?

C.1.10 Power bill dates :

from...

C.1.11

to...

Electricity

Gas

C.1.12 Did you go away over the time covered by this account?

if yes, For how long (number of days)

C.1.13 Have you ever had an energy audit done on your home?

1 =yes 2= no

C.1.14 Have you ever made home improvements to improve energy efficiency

1 = yes 2 = no

C.1.15 If yes - what done?

N/A = not applicable

C.1.16 Using the scale on card 7, how would you rate your household's energy consumption?

1= very high 2= above average 3= average
4= below average 5= very low -9 =Don't know

C.1.17 How would you describe the weather today (see card 8)?

1 = hot; 2= warm 3= cool 4= cold

C.1.18 Would you describe conditions today

1= comfortable 2 = uncomfortable for you

D PHYSICAL CHARACTERISTICS OF DWELLING

D.1 ROOM CHARACTERISTICS

D.1.1 Has the home had any major renovation /additions that you know of?

1 = additions 2 = renovation 3=none 9=don't know

D.1.2 Give brief description and when (N/A or -999 if not applicable)

.....

.....

D.1.3 *In this dwelling how many of the following types of rooms are there and how many of them are / are not carpeted?*
(go across ways)

<u>Room Types</u>	No. of rooms with carpets	No. of rooms without carpets
<u>Bedrooms:</u> eg. Bedrooms or rooms used as bedrooms including sleep out		
<u>Living areas/rooms:</u> eg lounge/family room etc/ kitchen with sitting area/dining room/ rumpus room		
<u>Utility rooms:</u> eg kitchen, studies, hobby room, sewing room, garages used for hobbies etc		
Total Number of Rooms		

D.2 HEATING

D.2.1 *In the winter season (usually May to August) what times of the day do you usually heat each of the three thermal zones? (see card 9)*

(multiple answers accepted)

put each relevant time period on the table below

1. 7am to 9am (morning)
2. 9am to 5pm (day)
3. 5pm to 11 pm (evening)
4. 11pm to 7am (night)
5. no heating

<u>Room Types</u>	Heating schedule on Weekdays	Heating schedule on Weekends
<u>Bedrooms:</u> eg. Bedrooms or rooms used as bedrooms including sleep out		
<u>Living areas/rooms:</u> eg lounge/family room etc/ kitchen with sitting area/dining room/ rumpus room		
<u>Utility rooms:</u> eg kitchen, studies, hobby room, sewing room, garages used for hobbies etc		

D.3 PHYSICAL

D.3.1 *Do you have a garage which is regularly used as a work or play area?*

1= have garage and it is used as a work or play area 2=no, don't have a garage 3=have garage but not used as a work or play area regularly

D.3.2 *Thinking about outside walls, from card 10, can you tell me what is the basic shape of your house?*

1 = 'squarish' 2 = rectangular 3 = L-shaped 4 = U-shaped 5 = T-shaped 6 = Z-shaped 7 = cross-shaped

D.4 HOUSE AIR LEAKAGE

D.4.1 How would you rate the house air tightness (see card 11)

1 = airtight 2 = average 3 = leaky 4 = draughty

D.4

D.4.2 When the house is left empty for 8 hours or more, how many windows would you leave open while you are away?

D.4 1 = a few 2 = most of them 3 = all 4 = none

D.4.3 When at home, approximately how many windows would you leave open?

D.4 1 = a few 2 = most of them 3 = all 4 = none

on a hot day?
on a mild day?
on a cold day?

D.4

D.4.4 Do you have ventilators in your windows?

1 = yes 2 = no

D.4.5 Are the ventilators functional or have they been blocked off or permanently closed?

1 = functional 2 = blocked/permanently closed -999 = not applicable

D.4.6 How many of your windows have these ventilators?

-999 = not applicable

D.4.7 Do you have any passive stack vents?

1 = yes 2 = no -999 = not applicable

D.4.8 How many?

-999 = not applicable

D.4.9 Wind exposure (see card 12)

1 = sheltered 2 = medium sheltered 3 = medium exposed 4 = exposed

Wind Exposure Classes

D.4.10 Does your house suffer from mould growth or excessive condensation?

1 = yes 2 = No

D.4.11 In how many rooms? (N/A if they don't have that type of room)

Bathrooms?

(0, 1, 2, ... or N/A)

Kitchen?

(0, 1, 2, ... or N/A)

Bedrooms?

(0, 1, 2, ... or N/A)

Other?

(0, 1, 2, ... or N/A)

Please specify room

D.4.12 After having been shut up for more than a day does your house smell musty?

1 = yes 2 = no

--

D.4.13 What are the window frames of the majority of windows made of?

1 = aluminium 2 = wood 3 = combination/mix

--

D.4.14 How many of your heated areas have thermal/heavy drapes which you usually close overnight during the winter?

(no. of rooms)

Living, Lounge and Dining Rooms

Bedrooms

Service Areas

D.4.15 Do you leave the windows with thermal drapes open during the night?

1 = yes 2 = no -999 = Not applicable (no thermal curtains)

--

D.4.16 Are any unused chimneys blocked up or closed off?

1 = yes 2 = no -999 = Not applicable

--

D.4.17 If so, how many?

-999 = Not applicable

--

E PHYSICAL CHARACTERISTICS OF DWELLING
(NOW WITH SETUP SHEETS)

F CONSERVATION/POWER SAVING

F.1.1 Suppose that you had to cut down the amount of energy you used in the home. In what order would you reduce your use in the areas listed on card 13?

water heating		electric appliances (mixers etc)	
home heating		TV/music/entertainment	
lighting		Electric blankets	

(rank them, with 1 being the first area you would cut down in, 2 for the second etc

F.1.2 What other things could your household do to save energy at home if necessary?

.....

F.1.3 If you had the money, what modifications or improvements would you make to your home to reduce energy consumption?

.....

F.1.4 Do you currently do any of the following:

Practise recycling of glass, cans, paper or plastic?

Actively use energy saving practises in order to conserve energy?

Use public transport as an alternative to car use, rather than thou necessity?

Belong to a conservation or environmental organisation?.

if yes - which one?

G BACKGROUND DETAILS ON OCCUPANTS

G.1 ETHNICITY AND EDUCATION

G.1.1 For each occupant what are their ethnic backgrounds, employment situations and educations?

person no. & name (note keep same order as earlier questions A1.1 B1.2)		ethnic backgnd (card 14)	employment situation (card 15)	occupation (write it & code later)	highest qualification (card 16)
All under 15 year olds should be coded to NA for these three questions					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					

Ethnic codes (card 14)

1 = NZ European or Pakeha	9 = Tongan
2 = NZ Maori	10 = Niuean
6 = Other European	11 = Chinese
7 = Samoan	12 = Indian
8 = Cook Island Maori	13 = Other Asian
5 = Other	

Employment status codes: (card 15)

1 = currently in full-time paid employment	2 = currently in part-time paid employment
3 = self employed	4 = unemployed /not working
5 = home duties (housewife/house husband)	6 = retired
7 = student	NA = under 15 years old

Occupation codes :

1= legislators, administrators, managers	2 = professionals (science, health, teaching, law etc)
3 = technicians and associate professionals	4 = clerks
5 = service & sales workers	6 = agriculture & fishery workers
7 = trades workers	8 = plant & machinery operators & assemblers
9 = elementary occup (labourers, etc)	0 11 = armed services
10 = other	NA= retired/student/home duties or under 15 years old

Education codes: (card 16) Note: code only "attained qualifications" i.e. if currently in 6th form studying for 6th form certificate code would be 2 if they have achieved school cert in 1 or more subjects or code 1 if they do not have school cert in one or more subjects.

1= no school qualification	2 = school cert in 1 or more subjects
3 = 6th Form Cert or UE in 1 or more subj.	4 = University Bursary or scholarship
5 = Overseas qualification	6 = Trade certificate
7 = Nursing/ NZ cert/ technicians/teacher's certificate or diploma	8 = University degree
9 = other tertiary qualification	NA = under 15 years old

G.2 HOUSEHOLD INCOME

G.2.1 *How many occupants regularly contribute to the income of the household?*

G.2.2 *What is your household's main sources of income (and which are the most important) (see card 18)*

1 = most important etc 2 = second most important (tick sources)

	source	1 = most imp.
wages/salary;		
investments /dividends		
national super;		
benefit/allowance		
ACC/insurance		
Other		

And lastly:

G.2.3 *From card 19 please indicate what is the approximate total income of this household before taxes etc are taken out?*

	<i>per year</i>	<i>per week</i>
1 =	up to \$5,000 per yr;	(on average less than \$96 per week before tax)
2 =	\$5001 - \$10,000;	(\$96 to \$191 per week)
3 =	\$10,001 - \$15,000	(\$192 - \$287 per week)
4 =	\$15001 - \$20,000;	(\$288 - \$384 per week)
5 =	\$20,001 - \$25,000;	(\$385 - \$480 per week)
6 =	\$25,001 - \$30,000;	(\$481 - \$576 per week)
7 =	\$30,001 - \$40,000;	(\$577 - \$768 per week)
8 =	\$40,001 - \$50,000;	(\$769 - \$961 per week)
9 =	\$50,001 - \$60,000;	(\$962 - \$1153 per week)
10 =	\$60,001 - \$80,000;	(\$1154 - \$1538 per week)
11 =	\$80,001 - \$100,000,	(\$1539 - \$1923 per week)
12 =	over \$100,000	(\$1924 per week or over)
13 =	wouldn't say	
-9 =	don't know	

REMEMBER TO GET POWER BILL SIGNATURE

Inform house owners/tenants that we have obtained the house plans from the relevant city/district council.

"Thanks for your time and co-operation"

Subjective Assessment

Outside weather conditions..... temperature?

How does this house feel to you?

G.2.4 Does the house feel

1 = damp 2 = slightly damp 3 = neutral 4 = dry 5 = very dry

G.2.5 Does the house feel

1 = poorly ventilated 2 = neutral 3 = well ventilated

G.2.6 Does the house feel

1 = very cold 2 = cold 3 = neutral 4 = warm 5 = very warm.

Time taken for interview

Name of interviewer

I agree to allow BRANZ staff to access my power bill records solely for use in the HEEP investigation. The data will not be released to any third party.

Name of occupant

Signature

Date

G.2.7 Name of power company(s):

Electricity.....

Gas

G.2.8 Have you changed power companies in the last 5 years?

1 = yes 2 = no -9 = don't know

G.2.9 Please list previous power companies:

.....
.....
.....

I have received a payment of \$50 for participating in the Household Energy End Use Project.

Signature.....

Preferred Installation Times

.....
.....
.....

Landlord Details (if dwelling rented):

Name

Phone

H WALK THROUGH AUDIT

(To be used when no plans are available from the local council)

record:

1. room type
2. heating type and location
3. heating schedule
4. floor coverings - carpet/lino/tiles/etc
5. window size "WS" (% of wall area)
6. shading "S" (100% is completely shaded, 0% is unshaded)
7. north orientation
8. common walls with other buildings (mark with "X" and double line)
9. mould growth (mark on diagram using wiggly line)
10. Thermal drapes (indicate with a * by window with thermal drapes)

Example:

Windows:

If the plans are unavailable please use diagrams below to enter the answers to the following three questions.

**** Using card 12 (a) as a guide, approximately what percentage of each of the outside walls are windows? Start with the north facing wall, then work clockwise (ie east is next)**

H.1.1 How many of the windows on that wall are double glazed?

H.1.2 How much are they shaded during the heating season - May to August. (Card 12(b))?

Shading index:

1 = all day sun

2 = loses sun in the early afternoon

3 = loses sun in late afternoon

4 = doesn't receive sun until noon

5 = doesn't receive sun until early afternoon

6 = doesn't receive sun during noon hours (12 noon to 2 pm)
 7 = doesn't receive sun during most of the day

Orientation	Wall Area (incl. windows) (from plans or walk through audit diagram)	Window Area (taken off plans, otherwise established on-site using diagrams above)	Area of double glazed windows	Shading index (multiple indices are possible) [1 to 7]
North				
Northeast				
East				
Southeast				
South				
Southwest				
West				
Northwest				

REMEMBER:

TO INDICATE THE % SHADING ON PLANS OR ON DIAGRAM

(0% = completely unshaded, 100% = completely shaded)

TO INDICATE ON PLANS (OR WALK THROUGH AUDIT DIAGRAM) WITH A
 WRIGGLY LINE PLACES ON THE WALLS AND CEILING WHERE MOULD IS
 OBVIOUS

Appendix B

Effect on Operation Diagram & Lists

The Effect on Operation Diagram presented in chapter seven is appended in this section. In an effort to present this at a suitable scale, the diagram is blown up and is also split up to show each Effect on Operation formula part. At the end of this appendix the basic list form is also enclosed.

B-2 Whole diagram

B-3 Unknown Increase

B-4 Proportional change

B-5 Unchanged

B-6 List form

The "Effect on Operation" Approach

Proportional change <i>22 appliances</i>	Unchanged <i>40 appliances</i>	Unknown increase <i>21 appliances</i>
Deep Freeze Refrigerator Combination Fridge Freezer Rangehood Extractor Fan Fluorescent Lights-fixed Fluorescent Lights-portable Incandescent Lights-fixed Incandescent Lights-portable Halogen Lights-fixed Halogen Lights-portable Compact Fluorescent-fixed Compact Fluorescent-portable Cupboard Heaters Heated Fish Tank gas underfloor heating electric underfloor heating piped gas (flued) non central piped gas (unflued) non central electric nightstore	Iron Video Stereo Electric Lawnmower Weedeater Food Processor Mixer Breadmaker Wastemaster Vacuum cleaner Toaster Electric Jug Coffee Maker Induction Cooking Separate Electric Grill Separate Gas Grill Rice Cooker Barbeque (LPG) Barbeque (Charcoal) Barbeque (Electric) Computer/Games Electric Power Tools Electric Hobs Gas Oven (Gas or LPG) Gas Hobs (Gas or LPG) Wood/Coal Range Microwave Electric Frypan Bench top mini-oven Crockpot dehumidifier (with heater) portable convection heater open fire portable electric radiator Heated Towel Rail Dishwasher washing machine tumble dryer Cabinet dryer portable fan heater	Television Electric Range (hobs+stove) Gas Range (either Gas or LPG) Electric Oven Sewing Machine Heat Lamps Sky/Saturn Decoder double electric blanket single electric blanket LPG heater in-ceiling/wall heating wall fan heater electric panel heater OBSOLETE electric fan / radiator portable kerosene heater enclosed wood/coal burner electric radiators A.C. - Heat Pump Laptop Heater type not specified air conditioner (reverse cycle)

Appendix C: LCI data set

Embodied Energy Figures

The embodied energy LCA calculations are appended in this section. This relatively large data set is ordered alphabetically under each appliance category. The appendix also has a table of contents so any appliance can be looked up.

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General, small portable appliances

Cupboard heater	C-5
Extractor fan.....	C-5
Heated fish tank.....	C-5
Heated towel rail	C-6
Sewing machine	C-6
Vacuum cleaner.....	C-6

Entertainment appliances

Computer/games	C-7
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Washing and drying appliances

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Dishwasher.....	C-9
Iron	C-9
Tumble dryer.....	C-10
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Kitchen and cooking appliances

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Barbeque (electric)	C-11
Barbeque (LPG)	C-11
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Combination fridge freezer	C-12
Crockpot	C-13
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Electric fry pan.....	C-14
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Electric oven	C-16
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Electric weed eater	C-27
Gas weed eater	C-27

General, small portable appliances

Cupboard heater				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Paint - General	70	0.002		
PVC General	77.2	0.006		
Aluminium, virgin	217.69	0.6		
plastic - general	80.5	0.025		
Copper (Wiring)	60	0.082		
Silicon	2355	0.002		
Iron	25	0.002		
Manganese	52	0.002		
Stainless steel	56.7	0.5		
Glass, float	15.9	0.3		
		176.1337	44.0	in MJ/annum

Extractor fan				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
plastic - general	80.5	0.33		
Steel - general	20.1	0.55		
Aluminium, virgin	217.69	0.11		
galvanised steel	34.8	0.11		
Metal (Fixing screws)	34	0.0041		
Rubber	67	0.011		
		66.2703	6.6	in MJ/annum

Heated fish tank				
Life (in years)			20	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
PVC General	77.2	0.016		
plastic - general	80.5	0.35		
Copper (Wiring)	60	0.082		
Silicon	2355	0.05		
Iron	25	0.002		
Manganese	52	0.002		
Stainless steel	56.7	0.5		
copper virgin	57	0.028		
Steel	40	1		
Glass, toughened	22	3		
Glass - float	15	0.3		
Iron	25	0.0005		
Aluminium, virgin	217.69	1.33E-05		
cement - General	4.5	0.00284		
plastic - general	80.5	0.00993		
Silicon	2355	0.01224		
Mercury	87	2.5E-06		
argon	1459	0.00031		

		256.7854	12.8	in MJ/annum
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Heated towel rail				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	3.51		
copper virgin	57	0.13		
plastic - general	80.5	0.025		
Rubber	67	0.054		
		212.0575	106.0	in MJ/annum

Sewing machine				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
PVC Injection Moulding	95.1	2.9		
Copper (Wiring)	60	0.082		
plastic - general	80.5	0.87		
PVC General	77.2	0.006		
Aluminium, virgin	217.69	0.8		
Steel Virgin	35.4	1.16		
copper virgin	57	0.0464		
Chromium	83	0.0232		
Nickel 8	92.5	0.0116		
		573.1406	57.3	in MJ/annum

Vacuum cleaner				
Life (in years)			3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	0.459		
copper virgin	57	0.262		
plastic - general	80.5	1.075		
Rubber	67	0.002		
Steel Virgin	35.4	0.109		
		205.3838	68.5	in MJ/annum

Entertainment appliances				
Computer/games				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
ABS	95.3	2.54		
High Impact Polystyrene	87.4	1.68		
Low Density Polyethylene (LDPE) Resin	78.1	1.81		
Glass, toughened	27	6.98		
Lead Virgin	49	2.54		
Steel Virgin	35.4	9.07		
Aluminium, virgin	217.69	3.04		
Metal (Fixing screws)	34	1.04		
		1861.391	930.7	in MJ/annum

Separate radio cassette				
Life (in years)			3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	1.041667		
Copper (Wiring)	60	0.082		
Aluminium, virgin	217.69	0.1375		
plastic - general	80.5	0.804167		
Iron	25	0.472222		
PVC General	77.2	0.006		
paper	24.8	0.00025		
		148.7377	49.6	in MJ/annum

Stereo				
Life (in years)			3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	3.75		
Copper (Wiring)	60	0.082		
Aluminium, virgin	217.69	0.495		
plastic - general	80.5	2.895		
Iron	25	1.7		
PVC General	77.2	0.006		
paper	24.8	0.0009		
		521.4596	173.8	in MJ/annum

Television				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	0.33		
copper virgin	57	0.92		
Glass, toughened	27	24.55		
Iron	25	2.58		
Lead Virgin	49	0.12		

Nickel	164	0.53		
Sealant epoxide Resin	137	0.7		
plastic - general	80.5	13		
		2086.828	208.7	in MJ/annum

Television decoder				
Life (in years)			5	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	2.5		
copper virgin	57	0.3		
Aluminium, virgin	217.69	0.33		
plastic - general	80.5	1.13		
Lead Virgin	49	0.74		
		304.6627	60.9	in MJ/annum

Video				
Life (in years)			8	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	2.5		
copper virgin	57	0.3		
Aluminium, virgin	217.69	0.33		
plastic - general	80.5	1.13		
Lead Virgin	49	0.74		
		304.6627	38.1	in MJ/annum

Washing and drying appliances

Cabinet dryer				
Life (in years)			13	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Ceramics - General	10	0.24621		
Fibreglass	28	0.18561		
Metal (Fixing screws)	34	0.03788		
plastic - general	80.5	0.31197		
Rubber	67	1.06061		
Stainless steel	56.7	1.36854		
Steel Virgin	35.4	0.09091		
Insulation, fibreglass	32	0.18561		
Nickel 8	92.5	0.18561		
Chromium	83	0.03788		
plastic - general	80.5	0.00621		
Copper (Wiring)	60	0.006		
		213.048	16.4	in MJ/annum

Dishwasher				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Ceramics - General	10	3.25		
Fibreglass	28	0.15		
Metal (Fixing screws)	34	4.986		
plastic - general	80.5	4.118		
Rubber	67	0.511		
Stainless steel	56.7	1.865		
Steel Virgin	35.4	5.351		
		867.131	86.7	in MJ/annum

Iron				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Plastic	95	0.411		
Steel	40	0.519		
Copper (Wiring)	60	0.082		
Aluminium, virgin	217.69	0.038		
Rubber	67	0.006		
Fabric	120	0.016		
		75.31922	18.8	in MJ/annum

Tumble dryer				
Life (in years)			13	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Ceramics - General	10	3.25		
Fibreglass	28	2.45		
Metal (Fixing screws)	34	0.5		
plastic - general	80.5	4.118		
Stainless steel	56.7	14		
Steel Virgin	35.4	18.0647		
Insulation, fibreglass	32	1.2		
Nickel 8	92.5	2.45		
Chromium	83	2.45		
Rubber	67	0.5		
Copper (Wiring)	60	0.082		
		2389.69	183.8	in MJ/annum

Washing machine				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	25.11		
Polypropylene, Orientated Film	99.2	16.83		
Stainless steel	56.7	5.69		
Cast Iron	70	9.28		
MDF	12	2.31		
Glass, toughened	27	2.39		
General Polyethylene	83.1	0.56		
Rubber	67	1.94		
copper virgin	57	1.68		
Aluminium - Virgin	217.6935	1.33		
Ceramics - General	10	0.53		
Hardboard	16	0.47		
Glass, float	15.9	0.02		
		4197.85	279.9	in MJ/annum

Kitchen and cooking appliances

Barbeque (charcoal)				
Life (in years)			7	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Nylon (Polyamide) 6 Polymer	120.5	2		
Stainless steel	56.7	4		
Steel - general	20.1	8		
Metal (Fixing screws)	34	0.082		
Paint - General	70	0.008		
Aluminium, virgin	217.69	0.01		
Ceramics - General	10	0.008		
		634.205	90.6	in MJ/annum

Barbeque (electric)				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	8		
Nylon (Polyamide) 6 Polymer	120.5	3		
Aluminium, virgin	217.69	2		
Copper (Wiring)	60	0.082		
PVC General	77.2	0.006		
Metal (Fixing screws)	34	0.082		
plastic - general	80.5	0.004		
Nickel 8	92.5	0.7		
Cast Iron	70	4		
Chromium	83	0.7		
		1661.82	415.5	in MJ/annum

Barbeque (LPG)				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	48		
Nylon (Polyamide) 6 Polymer	120.5	3		
Aluminium, virgin	217.69	5		
Steel - general	20.1	7		
Rubber	67	0.5		
Metal (Fixing screws)	34	0.082		
		4348.54	1087.1	in MJ/annum

Bench top mini-oven				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	7.42788		
Glass, toughened	27	1.03645		
Aluminium, virgin	217.69	0.01555		
Paint - General	70	1.24374		

copper virgin	57	0.03109		
insulation - general	45	0.19002		
PVC General	77.2	0.02073		
Zinc Virgin	72	0.03455		
		395.788	26.4	in MJ/annum

Bread maker				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	3		
Copper (Wiring)	60	0.082		
plastic - general	80.5	3		
Stainless steel	56.7	1		
Steel Virgin	35.4	0.4		
copper virgin	57	0.056		
PVC General	77.2	0.55		
Zinc Virgin	72	0.0018		
Nickel 8	92.5	0.25		
Chromium	83	0.25		
		1060.007	530.0	in MJ/annum

Coffee maker				
Life (in years)			6	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	0.255		
paper	24.8	0.007		
copper virgin	57	0.055		
Glass, toughened	27	0.33		
plastic - general	80.5	0.88		
Rubber	67	0.034		
Steel Virgin	35.4	0.018		
		141.4848	23.6	in MJ/annum

Combination fridge freezer				
Life (in years)			14	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel	40	47.55		
Cast Iron	70	4.56		
Aluminium, virgin	217.69	2.11		
Copper tube	70.6	2.87		
Metal (Fixing screws)	34	0.25		
Rubber	67	0.17		
Fabric	120	0.08		
Plastic	95	23.48		
Insulation, fibreglass	32	0.08		
Glass, float	15.9	2.87		
Refrigerant fluid 8	49.1	0.08		
Shell 320 oil 8	43.1	0.17		

		5202.686	371.6	in MJ/annum
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Crockpot				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	0.14		
Aluminium, virgin	217.69	0.7		
Paint - General	70	0.004		
copper virgin	57	0.13		
plastic - general	80.5	0.04		
Glass, toughened	27	0.33		
Nickel 8	92.5	0.1		
Chromium	83	0.1		
Rubber	67	0.006		
		194.709	48.7	in MJ/annum

Deep freeze				
Life (in years)			14	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	38.22		
Copper tube	70.6	1.68		
Copper (Wiring)	60	1.56		
Aluminium, virgin	217.69	1.07		
Metal (Fixing screws)	34	0.07		
ABS	95.3	61.9		
PVC General	77.2	2.2		
plastic - general	80.5	25.08		
Mastic Sealant	200	1.55		
Shell 320 oil 8	43.1	0.24		
Refrigerant fluid 8	49.1	0.18		
Glass, toughened	27	0.24		
		11038.1	788.4	in MJ/annum

Food processor				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	0.046		
copper virgin	57	0.028		
Brass virgin	80	0.037		
Bronze	69	0.001		
Fibreglass	28	0.003		
plastic - general	80.5	0.962		
Rubber	67	0.012		
Stainless steel	56.7	0.499		
		121.261	30.3	in MJ/annum

Electric fry pan				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	2.1966		
Nylon (Polyamide) 6 Polymer	120.5	0.82372		
Aluminium, virgin	217.69	0.54915		
Copper (Wiring)	60	0.082		
PVC General	77.2	0.006		
Metal (Fixing screws)	34	0.02252		
plastic - general	80.5	0.0011		
Nickel 8	92.5	0.1922		
Cast Iron	70	1.0983		
Chromium	83	0.1922		
		460.199	115.0	in MJ/annum

Separate electric grill				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	11		
Aluminium, virgin	217.69	0.0225		
Paint - General	70	1.8		
copper virgin	57	0.045		
insulation - general	45	0.275		
PVC General	77.2	0.03		
Zinc Virgin	72	0.05		
		541.154	36.1	in MJ/annum

Separate gas grill				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	11		
Aluminium, virgin	217.69	0.0225		
Paint - General	70	1.8		
copper virgin	57	0.045		
insulation - general	45	0.275		
PVC General	77.2	0.03		
Zinc Virgin	72	0.05		
		541.154	36.1	in MJ/annum

Electric hobs				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	4.601		
Glass, toughened	27	0.642		
Aluminium, virgin	217.69	0.010		
Paint - General	70	0.770		

copper virgin	57	0.019		
insulation - general	45	0.118		
PVC General	77.2	0.013		
Zinc Virgin	72	0.021		
		245.16	24.5	in MJ/annum

Gas hobs (either gas or LPG)				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	8.6		
Glass, toughened	27	1.2		
Aluminium, virgin	217.69	0.018		
Paint - General	70	1.44		
copper virgin	57	0.036		
insulation - general	45	0.22		
PVC General	77.2	0.024		
Zinc Virgin	72	0.04		
		458.243	45.8	in MJ/annum

Induction hobs				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Metal (Fixing screws)	34	0.0002		
Ceramics - General	10	0.0004		
Polycarbonate	112.9	0.0045		
Aluminium, virgin	217.69	0.0229		
Steel	40	0.0434		
Tin	250	0.0594		
copper virgin	57	0.3153		
		40.0524	2.7	in MJ/annum

Electric jug (kettle)				
Life (in years)			3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Polypropylene, Injection Moulding	115.1	0.15		
Stainless steel	56.7	0.8		
PVC General	77.2	0.006		
Copper tube	70.6	0.055		
Copper (Wiring)	60	0.082		
		71.8912	24.0	in MJ/annum
Microwave				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	16.4		
copper virgin	57	0.897		
Aluminium, virgin	217.69	0.897		

plastic - general	80.5	0.874		
Toughened Glass	23.5	1.61		
Lead Virgin	49	2.323		
		1048.98	104.9	in MJ/annum

Mixer				
Life (in years)			5	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel	40	0.537		
Metal (Fixing screws)	34	0.0036		
plastic - general	80.5	0.5345		
Rubber	67	0.032		
Silicon	2355	0.021		
Glass, toughened	27	1.286		
MDF	12	0.001		
Brass virgin	80	0.01		
		151.7627	30.4	in MJ/annum

Electric oven				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	43		
Glass, toughened	27	6		
Aluminium, virgin	217.69	0.09		
Paint - General	70	7.2		
copper virgin	57	0.18		
insulation - general	45	1.1		
PVC General	77.2	0.12		
Zinc Virgin	72	0.2		
		2291.22	152.7	in MJ/annum

Gas oven (either gas or LPG)				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	43		
Glass, toughened	27	6		
Aluminium, virgin	217.69	0.09		
Paint - General	70	7.2		
copper virgin	57	0.18		
insulation - general	45	1.1		
PVC General	77.2	0.12		
Zinc Virgin	72	0.2		
		2291.22	152.7	in MJ/annum

Electric range (hobs+stove)				
Life (in years)			15	

<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	47.601		
Glass, toughened	27	6.642		
Aluminium, virgin	217.69	0.09963		
Paint - General	70	7.9704		
copper virgin	57	0.19926		
insulation - general	45	1.2177		
PVC General	77.2	0.13284		
Zinc Virgin	72	0.2214		
		2536.38	169.1	in MJ/annum

Gas range (either gas or LPG)				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	51.6		
Glass, toughened	27	7.2		
Aluminium, virgin	217.69	0.108		
Paint - General	70	8.64		
copper virgin	57	0.216		
Fibreglass	28	1.32		
PVC General	77.2	0.144		
Zinc Virgin	72	0.24		
		2727.02	181.8	in MJ/annum

Wood/coal range				
Life (in years)			15	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	150		
Glass, toughened	27	1		
Aluminium, virgin	217.69	0.1		
Paint - General	70	7.2		
copper virgin	57	0.2		
insulation - general	45	3		
PVC General	77.2	0.2		
Zinc Virgin	72	0.2		
		6039.01	402.6	in MJ/annum

Range hood				
Life (in years)			14	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
plastic - general	80.5	0.65		
Stainless steel	56.7	6.5		
Steel - general	20.1	0.4		
Aluminium, virgin	217.69	0.5		
Metal (Fixing screws)	34	0.0082		

Copper (Wiring)	60	0.164		
Rubber	67	0.5		
Aluminium - Virgin	217.6935	0.00115		
argon	1459	0.000137		
Cement, average NZ	6.2	0.00145		
copper virgin	57	0.001038		
Glass - float	15	0.02054		
Nickel	164	0.000084		
argon	1459	0.000024		
argon	1459	0.000002		
Tin	250	0.000145		
Titanium virgin	745	0.00001		
argon	1459	0.000017		
		632.6495	45.2	in MJ/annum

Refrigerator				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	21.5		
Iron	25	2		
copper virgin	57	2		
plastic - general	80.5	22		
Toughened Glass	23.5	0.5		
Aluminium, virgin	217.69	1		
Lead Virgin	49	1		
		2974.54	297.5	in MJ/annum

Rice cooker				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	0.14		
Aluminium, virgin	217.69	0.7		
Paint - General	70	0.004		
copper virgin	57	0.13		
plastic - general	80.5	0.04		
Glass, toughened	27	0.33		
Chromium	83	0.1		
Nickel 8	92.5	0.1		
PVC General	77.2	0.006		
		195.172	48.8	in MJ/annum

Toaster				
Life (in years)			6	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	0.62		
Aluminium, virgin	217.69	0.02		

copper virgin	57	0.06		
plastic - general	80.5	0.4		
		75.1278	12.5	in MJ/annum

Waste master				
Life (in years)			12	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
copper virgin	57	0.028		
Copper (Wiring)	60	0.082		
plastic - general	80.5	1.5708		
Rubber	67	0.01		
Steel Virgin	35.4	1.497		
Iron	25	0.51128		
PVC Pipe	67.5	2		
Aluminium, virgin	217.69	0.1232		
Glass, float	15.9	0.00616		
Cotton, Fabric	143	0.000616		
Nylon (Polyamide) 6 Polymer	120.5	0.1848		
Metal (Fixing screws)	34	0.006		
		383.889	32.0	in MJ/annum

Space heating appliances				
Double electric blanket				
Life (in years)			5	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Cotton, Fabric	143	1.4		
Cotton, Padding	27.1	1.4		
PVC General	77.2	0.012		
Copper tube	70.6	0.8		
plastic - general	80.5	0.4		
Copper (Wiring)	60	0.164		
		337.5864	75.0	in MJ/annum

Single electric blanket				
Life (in years)			5	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Cotton, Fabric	143	0.7		
Cotton, Padding	27.1	0.7		
PVC General	77.2	0.006		
copper virgin	57	0.4		
plastic - general	80.5	0.2		
Copper (Wiring)	60	0.082		
		163.3532	36.3	in MJ/annum

Portable convection heater				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Nickel 8	92.5	0.3		
Chromium	83	0.3		
PVC General	77.2	0.006		
Steel	40	1		
plastic - general	80.5	0.25		
Shell 320 oil 8	43.1	0.8		
Copper (Wiring)	60	0.082		
		152.6382	15.3	in MJ/annum

Dehumidifier (with heater)				
Life (in years)			8	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
PVC General	77.2	0.012		
Copper (Wiring)	60	0.164		
Aluminium, virgin	217.69	5		
Metal (Fixing screws)	34	0.006		
ABS	95.3	0.2		
PVC General	77.2	0.314286		
plastic - general	80.5	13		

Mastic Sealant	200	0.3875		
Shell 320 oil 8	43.1	0.034286		
Refrigerant fluid 8	49.1	0.025714		
Nickel 8	92.5	0.5		
Chromium	83	0.5		
		2357.234	294.7	in MJ/annum

Portable fan heater				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
copper virgin	57	0.12		
PVC General	77.2	0.006		
Steel	40	0.2		
plastic - general	80.5	1		
Copper (Wiring)	60	0.082		
		100.7232	10.1	in MJ/annum

Portable kerosene heater				
Life (in years)			6	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Insulation, fibreglass	32	0.0002		
Shell 320 oil 8	43.1	0.3		
Aluminium, virgin	217.69	2		
Steel Virgin	35.4	6		
plastic - general	80.5	1.5		
Cotton, Fabric	143	0.0005		
Glass, toughened	27	3		
Iron	25	0.001		
		862.5629	143.8	in MJ/annum

LPG heater				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Stainless steel	56.7	4		
Rubber	67	0.5		
Steel Virgin	35.4	1.5		
Nylon (Polyamide) 6 Polymer	120.5	1.5		
copper virgin	57	0.5		
Metal (Fixing screws)	34	0.1		
		526.05	131.5	in MJ/annum

Electric panel heater				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium, virgin	217.69	6.4		
Ceramics - General	10	1.6		

Shell 320 oil 8	43.1	3.5		
		1560.066	156.0	in MJ/annum

Electric radiator				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Quartz powder	0.852	1.4		
Ceramics - General	10	0.1		
Rubber	67	0.006		
Steel	40	1.7		
Copper (Wiring)	60	0.082		
		75.5148	7.6	in MJ/annum

Obsolete electric fan / bar radiator				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Quartz powder	0.852	4.3		
Ceramics - General	10	0.3		
Rubber	67	0.006		
Steel	40	5.3		
Copper (Wiring)	60	0.082		
		223.9856	22.4	in MJ/annum

Portable electric radiator				
Life (in years)			10	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Quartz powder	0.852	0.7		
Ceramics - General	10	0.05		
Rubber	67	0.006		
Steel	40	0.85		
Copper (Wiring)	60	0.082		
		40.4184	4.0	in MJ/annum

Lighting				
Compact fluorescent-fixed				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Glass - float	15	0.01779		
Iron	25	0.0005		
Aluminium, virgin	217.69	1.33E-05		
cement - General	4.5	0.00284		
plastic - general	80.5	0.00993		
Silicon	2355	0.01224		
Mercury	87	2.5E-06		
argon	1459	0.00031		
		30.3721	7.6	in MJ/annum

Compact fluorescent-portable				
Life (in years)			4	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Glass - float	15	0.01779		
Iron	25	0.0005		
Aluminium, virgin	217.69	1.33E-05		
cement - General	4.5	0.00284		
plastic - general	80.5	0.00993		
Silicon	2355	0.01224		
Mercury	87	2.5E-06		
argon	1459	0.00031		
		30.3721	7.6	in MJ/annum

Halogen lights-fixed				
Life (in years)			0.6	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium - Virgin	217.6935	0.00117		
argon	1459	0.00004		
Cement, average NZ	6.2	0.00145		
copper virgin	57	0.00008		
Glass - float	15	0.02054		
Nickel	164	0.000084		
Tin	250	0.000145		
Steel Virgin	35.4	0.0002		
Zinc Virgin	72	0.00004		
		0.694697	1.2	in MJ/annum

Halogen lights-portable				
Life (in years)			0.6	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium - Virgin	217.6935	0.00117		
argon	1459	0.00004		

Cement, average NZ	6.2	0.00145		
copper virgin	57	0.00008		
Glass - float	15	0.02054		
Nickel	164	0.000084		
Tin	250	0.000145		
Steel Virgin	35.4	0.0002		
Zinc Virgin	72	0.00004		
		0.694697	1.2	in MJ/annum

Heat lamps				
Life (in years)			0.3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium - Virgin	217.6935	0.00115		
argon	1459	0.000137		
Cement, average NZ	6.2	0.00145		
copper virgin	57	3.75E-05		
Glass - float	15	0.02054		
Nickel	164	0.000084		
argon	1459	0.000024		
argon	1459	0.000002		
Tin	250	0.000145		
Titanium virgin	745	0.00001		
argon	1459	0.000017		
Quartz powder	0.852	0.00001		
		0.88968	3.0	in MJ/annum

Incandescent lights-fixed				
Life (in years)			0.3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Cast Aluminium - Virgin	225.5	0.00115		
argon	1459	0.000137		
Cement, average NZ	6.2	0.00145		
copper virgin	57	3.75E-05		
Glass - float	15	0.02054		
Nickel	164	0.000084		
argon	1459	0.000024		
argon	1459	0.000002		
Tin	250	0.000145		
Titanium virgin	745	0.00001		
argon	1459	0.000017		
		0.898649	3.0	in MJ/annum

Incandescent lights-portable				
Life (in years)			0.3	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Aluminium - Virgin	217.6935	0.00115		
argon	1459	0.000137		
Cement, average NZ	6.2	0.00145		

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copper virgin	57	3.75E-05		
Glass - float	15	0.02054		
Nickel	164	0.000084		
argon	1459	0.000024		
argon	1459	0.000002		
Tin	250	0.000145		
Titanium virgin	745	0.00001		
argon	1459	0.000017		
		0.889671	3.0	in MJ/annum

Garage and garden				
Electric lawnmower				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
ABS	95.3	3.08		
Aluminium, virgin	217.69	0.072		
High Impact Polystyrene	87.4	3.252		
copper virgin	57	0.512		
High Density Polyethylene (HDPE) Resin	76.7	0.137		
Iron	25	0.013		
Nickel 8	92.5	0.027		
Shell 320 oil 8	43.1	0.323		
Nylon (Polyamide) 6 Polymer	120.5	0.029		
Nylon (polyamide) 6,6 Polymer	138.6	0.417		
General Polyethylene	83.1	0.002		
plastic - general	80.5	0.155		
Polypropylene, Injection Moulding	115.1	0.002		
General Purpose Polystyrene	86.4	1.69		
Steel Virgin	35.4	2.563		
		960.769	480.4	in MJ/annum

Gas lawnmower				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
Steel Virgin	35.4	21.2706		
Manganese	52	0.025		
Silicon	2355	0.123		
Chromium	83	0.005		
Vanadium	3710	0.0003		
Titanium virgin	745	0.0001		
Aluminium, virgin	217.69	7.332		
Aluminium, recycled	9	0.3		
Copper virgin	57	0.1538		
Zinc virgin	72	0.0216		
Steel wire, galvanised 6	29	1.222		
High Density Polyethylene (HDPE) Resin	76.7	4.225		
ABS	95.3	0.545		
PVC General	77.2	0.159		
Plastic	95	1.3002		
Rubber	67	0.0402		
Iron	25	1.6412		
Shell 320 oil 8	43.1	0.035		
Lead - general	25.21	0.75		
		2569.73	1284.9	in MJ/annum

Electric power tools				
Life (in years)			1	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		

copper virgin	57	0.028		
plastic - general	80.5	0.2		
Rubber	67	0.01		
Steel Virgin		1		
Iron		0.00904		
Aluminium, virgin		0.00452		
Metal (Fixing screws)		0.006		
Lithium		0.05		
PVC Injection Moulding		0.904		
Nylon (Polyamide) 6 Polymer		0.006		
		18.366	18.4	in MJ/annum

Electric weed eater				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
plastic - general	80.5	2.6012		
Nylon (Polyamide) 6 Polymer	120.5	0.0168		
PVC General	77.2	0.012		
Copper (wiring)	60	0.082		
Metal (Fixing screws)	34	0.0056		
Steel - general	20.1	2.6012		
Aluminium - General	155	0.0224		
		273.214	136.6	in MJ/annum

Gas weed eater				
Life (in years)			2	
<i>What material?</i>	<i>Output</i>	<i>Weights</i>		
plastic - general	80.5	2.6012		
Nylon (Polyamide) 6 Polymer	120.5	0.0168		
Shell 320 oil 8	43.1	0.323		
Metal (Fixing screws)	34	0.0056		
Steel - general	20.1	2.6012		
Aluminium - General	155	0.0224		
		281.2888	140.6	in MJ/annum

Appendix D

Electricity Generation Calculations

Enclosed in this appendix are all energy data calculations completed for electricity generation figures established in chapter three. The calculation of the solely renewable electricity mix figure is also included in the tables appended here.

1980						
	renewable					
Source	Hydro	Geothermal	Wind			
GWH	19171	1206	363			
EE	4653.15534	503.4757282	112.4563107	=	5269.087379	
%	84.60	5.32	1.60	91.5	6.0	ee %
				20741	91.5	%
	Non-renewable					
Source	Coal	Oil	Gas		TOTAL	22660
GWH	426		1494			
EE	6982.188879		76064.77493	=	83046.96381	
%	1.88		6.59	8.5	94.0	ee %
				1959	8.6	%

Today						
	renewable					
Source	Hydro	Geothermal	Wind			
GWH	24093	6847	2777			
EE	3139.115912	1534.423519	461.8136593	=	5135.35309	
%	57.07	16.22	6.58	79.9	2.54	ee %
				33717	79.9	%
	Non-renewable					
Source	Coal	Oil	Gas		TOTAL	42213
GWH	1855	6	6602			
EE	16320.73058		180435.5862	=	196756.3168	
%	4.39	0.10	15.64	20.1	97.46	ee %
				8475	20.1	%

Future if 100% renewable					
	renewable				
Source	Hydro	Geothermal	Wind		
GWH	24093	6847	2777		
EE	3447.420091	2204.741553	983.7616438	=	6635.923288
	27454	10208	6138		
%	62.68	23.31	14.01	100.0	100.00
				43800	100.0