DEVELOPING A MODEL FOR CARBON NEUTRAL SETTLEMENTS:

A MINE SITE VILLAGE CASE STUDY

This thesis is presented for the Degree of
Doctor of Philosophy
of
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School of Engineering and Information Technology

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material, which has been accepted for the award of any other degree or diploma other than that in the following disclosure:

The thesis contains material from “Mine Site Village Carbon Emissions & Engineering Offset Solutions” by Maxime Ploumis, a report submitted for the degree of Bachelor of Engineering, Murdoch University, Perth, Western Australia.

The report was written to satisfy the degree requirements of a 4th year industry internship. The internship represented 12 points out of 24 points of the engineering final year (equivalent to a one semester full-time unit). I negotiated and independently secured funding from WorleyParsons Ltd to support my research and subsequently arranged for contracts between Murdoch University and WorleyParsons to support the internship and appointed Maxime Ploumis as my research assistant. Together we designed and installed a monitoring system for Mt Magnet Gold mine site village followed up by several site visits. I also secured substantial funding to cover the cost of the equipment. I supervised the work and provided a substantial proportion of the intellectual input in the analysis and development of Maxime’s report. He made use of the collected data, developed several figures and tables in his final report, some of which are cited in the thesis.

Signature:

Abstract

The built environment in Australia is responsible for around 40 percent of the nations' greenhouse gases. Consequently carbon neutral buildings and precincts are areas of increasing interest to sustainability practitioners and researchers.

This thesis focuses on mine site village development as a contribution to an Australian Research Council research project entitled "Decarbonising Cities and Regions." It dissects the many areas of carbon emissions attributable to the construction and operation of a typical mine site village, how this carbon footprint can be reduced to a point of carbon neutrality, and how the process could be applied to other built formats. The scientific literature was found to be essentially silent on the issue of sustainability and carbon footprint of this type of built form.

Several research questions were posited regarding the carbon footprint: what are its constituents for a typical mine site village, how can it be calculated and substantially reduced or become 'carbon neutral'? After deducting the effects of energy efficiencies and behaviour change programs what effect does the introduction of renewable energy have in both standalone and grid connected configurations? After all aforementioned reductions what proportion remains to be offset by the introduction of accredited offset purchases?

A conceptual model was designed to delineate the components of the village's carbon footprint. These were the carbon emissions from: embodied energy of the built form; energy required to operate the village; transport of supplies to the village; fly-in/fly-out access by employees of the mine; water supply and waste water treatment; food production, and; solid waste disposal. The model was applied to a mine site village in Western Australia.

A life cycle analysis tool, eTool™, was used to determine the embodied energy of the built form and services infrastructure for village life spans of 5, 10, 15 and 20 years. A comprehensive on-site energy monitoring system was set up to measure the village's fossil fuelled operational energy; village deliveries were assessed on site; fly-in/fly-out emissions were calculated according to site visits and researched emissions from air travel; desalinated water and waste water treatment energy was monitored; and food consumption and solid waste were estimated. In addition a significant energy efficiency experiment was carried out to test a thermal ceramic coating applied to a typical mine site accommodation module (donga).

Methods to reduce carbon emissions were made by applying energy efficiencies and behaviour change to camp infrastructure and occupants, followed by determining potential penetration into the power generation system of appropriate renewable energy systems, and finally the purchase of accredited carbon sequestrating offsets.

Significant results can be summarized: total village carbon footprints for the life spans 5 to 20 years were calculated to be between 3233 and 2424 tonnes $CO_{2\text{-}e}$ per annum respectively, equating to 19 to 14.4 tonnes $CO_{2\text{-}e}$ per village worker annum, equivalent to the average Australian's domestic carbon footprint to which they would contribute when they return home. In terms of net present costing converting the village energy system to a standalone type gave a clear financial advantage to the owners in averting the capital expenditure of connecting the village to mine site generation plant. With a maximum penetration of 71 percent into the village's 1.09MWh energy consumption per annum the carbon reduction was small in terms of the village's overall footprint. The donga coating experiment resulted in a 10 percent saving in air conditioning energy consumption.

A generic model, LEVI (Low Energy Village Infrastructure) was developed in the form of an Excel workbook to provide a systematic method to calculate the carbon footprint of a built environment similar to that of a mine site village, such as caravan parks, remote tourism resorts, retirement villages, military camps, Aboriginal settlements and isolated research stations. LEVI was then applied specifically to the case study mine site village.

Further research is required to evaluate the potential of alternative village design and operation, for example, by means of comprehensive cost-benefit analysis or multi-criteria assessment of options. Isolated examples exist in the literature and this thesis highlights areas where so much more could be achieved in the vein of carbon reduction in the built environment.

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List of Abbreviations

AC	Air conditioning
ACCC	Australian Competition and Consumer Commission
BAU	Business as usual
BHP	BHP Billiton Ltd
BMS	Building management system
BoM	Bureau of Meteorology
CAPEX	Capital expenditure
CDM	Clean development mechanism
$CO_{2\text{-}e}$	Carbon dioxide equivalent
ESD	Ecologically sustainable development
FMG	Fortescue Metals Group
FWS	Four Wind Seasons
GFC	Global financial crisis
GWP	Global warming potential
GSHP	Ground source heat pump
IPCC	Intergovernmental Panel on Climate Change
IT	Information technology
LCA	Life cycle assessment
LGCs	Large-scale generation certificates (Renewable Energy Certificates)
LNG	Liquid natural gas
MMG	Mount Magnet Gold Village
NCOS	National Carbon Offset Standard
NGERS	National Greenhouse & Energy Reporting System
NPC	Net Present Cost
NPV	Net Present Value
OPEX	Operational expenditure

PV	Photovoltaic
RE	Renewable energy
RFID	Radio frequency identification
RMS	Remelius Resources Ltd, MMG mine site owners.
RTIO	Rio Tinto Iron Ore Ltd
SMEs	Small and medium enterprises
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute
WT	Wind turbine
WTP	Water treatment plant
WWTP	Waste water treatment plant

Acknowledgements

First of all I would like to express my deepest thanks to Dr Kuruvilla Mathew who is responsible for bringing me back to the halls of academia some thirty-four years since I last undertook the university challenge. Thank you for all your support and caring over the years and for driving me towards my childhood dream goal of becoming a doctor – healing the earth in this instance rather than people.

To my supervisor Distinguished Professor Goen Ho, I would like to thank you most sincerely for your guidance throughout my research and writing, and for your inimitable attention to detail and knowledge which have been invaluable. Your constant support and encouragement, with this occasionally stubborn student, has been greatly appreciated.

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To my children, Michael and Rhiannon, and my Granddaughter Charlotte, I dedicate all this effort. Lastly, Mum and Dad, I know how proud you both would be if you were here.

Publications

The following authored and co-authored publications are directly related to the writing of this thesis and can be regarded as contributing to it.

International Journal article

Goodfield, D., Anda, M. and Ho, G. (2014) *Carbon neutral mine site villages: Myth or reality?* Renewable Energy, 66. pp. 62-68.
- I drafted 90% of the paper with modifications based on my supervisors' comments.

Peer reviewed Conference Papers

Anda, M., Stewart, J., Goodfield, D., Ploumis, M. and Mathew, K. (2012) *Carbon Neutral Settlements: The role of solar energy.* In: AuSES 50th Annual Conference "SOLAR 2012 – the first 50 years, 6 - 7 December, Melbourne, Australia.
- I drafted 33% of the paper with modifications based on my supervisors' comments.

Lee, K., Murray, D., Goodfield, D. and Anda, M. (2012) *Experiences and issues for environmental science sensor network deployments.* In: 6th IEEE International Conference on Digital Ecosystem Technologies - Complex Environment Engineering, 18 - 20 June, Campione d'Italia, Italy pp.1-6.
- I drafted 25% of this paper modified by my co-authors.

Goodfield, D., Anda, M. and Ho, G. (2011) *Carbon neutral mine site accommodation village: Developing the model.* In: 19th International Congress on Modelling and Simulation - Sustaining Our Future: Understanding and Living with Uncertainty, MODSIM2011, 12 - 16 December, Perth, Western Australia pp. 3038-3044.
- I drafted 80% of this paper with modifications based on my supervisors' comments.

Goodfield, D., Stewart, J., .,Anda, M., Ho, G. and Mathew, K. (2011) *Carbon neutral village: The Australian model.* In: World Renewable Energy Congress, 8 - 13 May, Linköping, Sweden.
- I drafted 33% of the paper with modifications based on my supervisors' comments.

Anda, M., Stewart, J., Goodfield, D., Mathew, K., and Ho, G. (2011) *Towards carbon neutral villages: The six-step Model.* In: World Renewable Energy and Energy Efficiency Congress (WREEEC), 17 - 19 October, Bali, Indonesia.
- I drafted 33% of the paper with modifications based on my supervisors' comments.

Conference proceedings

Fourth International Conference on Climate Change: Impacts and Responses (2012). *Renewable Energy for Mine Site Villages: Carbon Offset.* Washington University, Seattle USA, 11-12th July.

World Renewable Energy Congress (2013). *Carbon Neutral Mine Site Villages: Myth or Reality?* Murdoch University, Perth, 14-18 July.

Fifth International Conference on Climate Change: Impacts and Responses (2013). *Carbon Neutral Mine Site Villages: Calculation & Offset Mechanism*. Port Louis, Mauritius, 18-19th July.

Sixth International Conference on Climate Change: Impacts and Responses (2014). *Energy Saving Properties of an Insulating Ceramic Coating*. University of Iceland, Reykjavik, Iceland, 27th – 28th July.

Drylands, Deserts & Desertification (2014). *Buildings and Carbon Emissions: Sources and Sustainable Solutions for Reduction.* Blaustein Institutes for Desert Research, Ben Gurion University of the Negev, Israel, 17 -20th November.

Chapter 1 - Introduction

1. INTRODUCTION

1.1 Background

Awareness of global warming and climate change, due substantially to ever-increasing concentrations in atmospheric carbon, is expressed universally in some form or other and demonstrated in most political circles. However, action to mitigate what has been regarded as the “greatest threat to mankind” varies considerably from business as usual to sweeping measures set in legislation. Irrespective of the political will or lack of it, local action takes place at all levels which ultimately has its effect at the political level. Nobel Laureate, Al Gore (2006) in his book and movie “An Inconvenient Truth” were effective across the globe in bringing about change through his unique and graphic exposure of the issues. The UK Stern Review (HM Treasury, 2006) and Garnaut Review (2008) in Australia both highlighted in detail the economic cost of ignoring the problem, as has US President Obama in the run up to the United Nations Climate Change Conference, COP-21, in November, 2015. The degree to which seminal economic reports and world leader warnings have been heeded by national governments has varied considerably, particularly in recent times in Australia. The UK has been, until late 2013, in economic decline following the global financial crisis of 2008 yet has forged ahead with a substantial raft of legislation and regulation to substantially reduce the nations’ carbon emissions, currently designed to reduce carbon emissions by 80 percent of 1990 levels by year 2050. On the other hand Australia, as one of a few developed nations not to suffer negative growth during this period, has a current target of a 26 to 28 percent reduction by 2030 based on 2005 levels, described by many commentators as being a weak response to a fundamentally urgent issue.

1.2 Climate Change and Greenhouse Gases (GHG)

Extended droughts, unseasonal heavy rainfall and flooding, landslides, crop failure, increased soil salinity, soil nutrient reduction, biodiversity and habitat loss on land and in the oceans, species extinction, increased health risks to animal and human welfare, are but a few of the obvious manifestations attributed to climate change by an ever increasing and deafening number of scientists across the globe. The United Nations Environment Programme is unequivocal in its advice that:

> "....to avoid the worst impacts from climate change, global CO_2 emissions must be cut by at least 50% by 2050."
>
> (UNEP, 2010: 2)

The IPCC, in its 5th report, after rigorous scientific observation and analysis is unequivocal:

> "Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes."
>
> (IPCC, 2013:17)

> "Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2."
>
> (ibid at 27)

UNEP advises that "GHG inventories for cities should follow the principles and methods developed by the IPCC," (UNEP, 2010:1) and accordingly this thesis follows that directive.

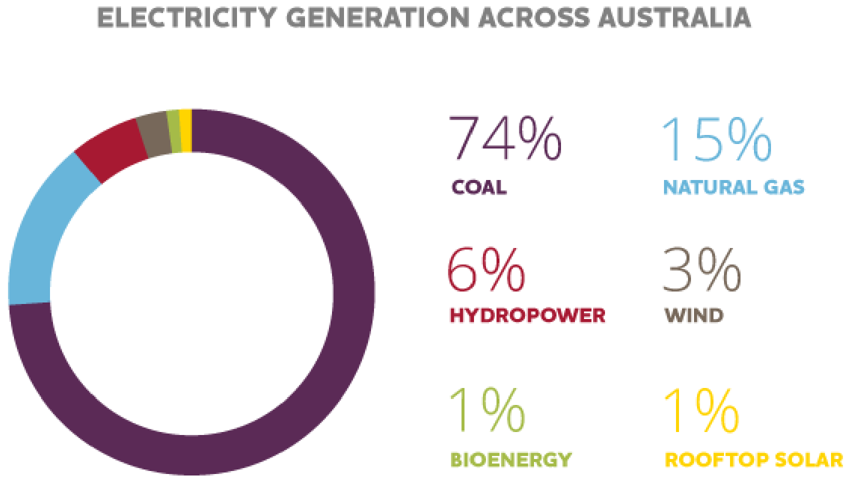
The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC) was adopted in 1995, came into force in early 2005 and set binding obligations on the industrialised nations to reduce their GHGs up to year end 2012. It was extended from expiry as the Doha Agreement and is now up for renewal as Kyoto II the terms of which will be vigorously debated at the COP-21 round of UNFCC talks in Paris in late 2015. The current

Australian Government has agreed to continue its longstanding agreement to reduce the nations' carbon emissions to 5 percent below 2000 levels by the year 2020 by way of its 'Direct Action Plan.' The centrepiece of the Plan is to source low cost emission reduction practices and technologies primarily through the financial incentives provided by the Emissions Reduction Fund (Clean Energy Regulator, 2015). These activities earn Australian carbon credit units, each unit equivalent to one tonne of carbon dioxide equivalent (tonnes $CO_{2\text{-}e}$) and can be accumulated to generate equity as a tradeable commodity, sold to the Australian Government through periodic auctions, or sold on the open market. Approved carbon abatement activities to gain Australian Carbon Credit Units (ACCUs) (DoE: 2013a) under the Fund, and concurrent legislation relating to farming practices, the Carbon Farming Initiative (Department of the Environment, 2014)), include: a multitude of activities involving farming livestock and crops; power generation; increase in biodiversity; and improved air quality.

According to a report prepared by Vivid Economics for The Climate Institute "Australia has slipped to 17 of the G20 nations" in terms of investment in carbon reduction methods and infrastructure (Climate Institute, 2013). Whether the Direct Action Fund manifests in an improvement in this situation remains to be seen.

1.3 The need for this research

The imperative to reduce atmospheric carbon has been well documented and demonstrably so with an increase in the severity and regularity of extreme weather events. The built environment represents a significant area of production of atmospheric carbon being responsible for up to 40% of global energy consumption and 30% of the world's carbon emissions (UNEP, 2009:3 and UNEP-SBCI, 2009:2). The built environment is clearly, therefore, an area where significant mitigation and reduction can take place as most processes involved in the construction and operation of buildings consume energy. Worldwide this energy is largely produced by the burning of fossil fuels, predominantly natural gas or coal and Australia is no exception (see figure 1.1 below). The burning of these fuels produces a significant proportion of the atmospheric carbon responsible for global warming and thence climate change.



Source: www.originenergy.com.au/4224/A-Z-of-Australias-Energy-Sources

Figure 1.1: Fuel sources for stationary energy production

1.3.1 Low carbon construction

The majority of energy consumed by the built form is consumed during its operation for active services such as heating, cooling, ventilating, lighting and appliance operation, the balance of between ten and twenty percent representing the embodied energy consumed during the process of construction, the production of the raw materials themselves and even demolition and site remediation.

The embodied energy is a constant, but annualised according to the life expectancy of the infrastructure the results can vary considerably. The annual emissions will decrease proportionally as the life span lengthens and visa-versa. In the context of mine site village development, where the projected life spans are frequently short, the annual proportions of the overall embodied energy can have a significant effect on the results. Villages will generally be planned to have a life expectancy of less than twenty years, if not in single digits, whilst the majority of residential and commercial buildings are constructed to have viable lives of a minimum of thirty years, with numerous examples around the world where buildings have serviceable lives of one hundred years or more.

The carbon emissions from the transport of goods and services, delivery of water, people and waste services to and from buildings, will be all or severally included according to where the boundaries in the LCA are drawn. Calculating the carbon footprint and reducing it to a point of carbon neutrality is one of the principal aims of the thesis. The terms ‘carbon neutral’ and LCA are dealt with in more detail in chapter 2.

Alternative approaches to decarbonising the economy

In view of the significant proportion of carbon emissions that the built form is responsible for, its decarbonisation can make a substantial contribution to atmospheric carbon reduction. Several different approaches can be adopted: one based on economic instruments; one where the market is left to capitalise upon carbon reduction technology development and practices; and individual and business activity on a voluntary basis.

The first approach was adopted by the previous Australian Labor Government which legislated for a price on carbon at $23 per tonne with annual incremental increases, coming into effect in 2012 and repealed in 2014 by the incoming Liberal Government. Administered by the Clean Energy Regulator the aim was to make big polluters pay for their emissions over set capped levels. This ‘carbon tax’ was due to morph into an emission trading scheme (ETS) wherein the price of carbon was to be set by the international market.

The current Australian Liberal Coalition Government has taken a radically different voluntary market approach whereby industry and individuals develop technologies and activities for purchase at periodic government auctions (see section 1.1.1 above).

A final and significant approach has been taken by individuals, SMEs, businesses and corporations who voluntarily invest in carbon reducing purchases and activities, such as roof-mounted solar panels to recycling all manners of putrescibles and recyclable wastes.

The thesis approaches the issue by researching mine site village development, a precinct similar to other built formats such as retirement villages, holiday homes, and caravan parks. The approach is to calculate the carbon footprint of the case study village and to develop sustainable methods of reduction of this footprint at least to a point of carbon neutrality.

1.3.2 Carbon emission calculation of a mine site village development

Black Cat Camp mine site village, in Mount Magnet (MMG), Western Australia (front cover) was selected as a typical mine site village for the determination of a precinct's carbon footprint and how to sustainably reduce it. A substantial part of the thesis details the monitoring and analysis of the stationery energy consumed to run MMG, the operational energy, followed by assessment of the emissions from processes essential to the village's daily function. As a gated community the boundaries of the elements to include in this carbon calculation are well defined.

MMG houses 162 residents on a rostered fly-in/fly-out basis travelling primarily from the Perth Metropolitan region, and is typical in its layout, construction and operation to the many mining camps throughout Australia and elsewhere. Reference is made in the literature review to visits to two Australian mining camps, but in terms of construction, layout and operation they vary little from MMG other than being considerably larger.

1.4 Research Questions, Aims and Objectives

The primary aim of this research is first to develop a conceptual model and tool by which the carbon emissions of mine site village development can be calculated and, secondly, to determine a method by which these emissions can be substantially reduced to a point where the development can be described as “carbon neutral.” A third aim is to determine whether the model and tool can be applied to similar precincts. The research requires a concentrated approach in order to understand how mine site villages are operated under normal working conditions.

In order to achieve the research aims the following questions are posited:

1. What are the constituents of the MMG carbon footprint and how are they calculated?
2. What is the carbon footprint of MMG, a typical mine site village?
3. What is the extent of carbon reduction when energy efficiency, behaviour change measures and renewable energy are applied and how much do they contribute to reducing MMG’s carbon footprint *en route* to carbon neutrality?
4. What is the appropriate renewable energy technology choice for MMG and what configuration will offset the stationary energy required for operation on a daily basis? How does renewable energy impact the overall carbon account in both standalone and mine site grid connected configurations?
5. What are the financial, technical and sustainability implications for standalone village power system power including the removal of the power supply line from the mine generating plant several kilometres away and does this distance have any material significance?
6. What are the financial implications of the various carbon reduction methods and how does the purchase of carbon offsets complete the carbon neutral emissions account?
7. Is the carbon neutral mine site village a viable proposition, or merely a desirable objective in the context of sustainable development of the built environment?

8. Are the metrics produced by the overall results applicable to model future carbon neutral villages of similar construction?

1.4.1 Components of carbon emission calculation

Seven generic sources of carbon emission were investigated as components of a typical mine site village carbon footprint calculation, as illustrated in figure 1.2, and are referred to in considerable detail in both the methodology, results and conclusions chapters:

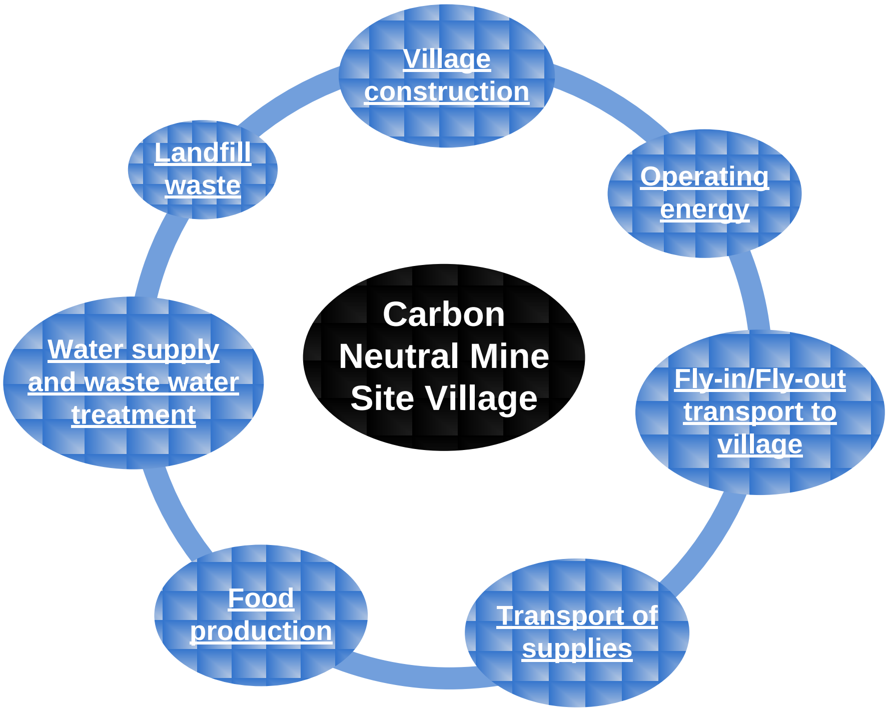


Figure 1.2: Components of the carbon footprint calculation for a mine site village.

1.5 Thesis Structure

Following this introduction the thesis has been divided into five further chapters in order to provide answers to the research questions set out in section 1.3. A brief synopsis of the chapters follows below:

1.5.1 Literature Review

This chapter opens with an overview of the broader issues concerning the atmospheric accumulation of GHGs and its effect on climate change. This is followed by some detail of carbon emission sources, the carbon cycle, and anthropocentric global warming with a brief mention of international agreements dealing with emission reduction. The term ‘carbon neutral’ is explained in some detail as one of the principal aims of the thesis is to develop a carbon neutral mine site village. Life cycle analysis is examined with some discussion of the international rules governing the procedure. Finally the review discusses low and zero carbon buildings, and several mine site village case studies focused on energy and water efficiency and carbon emission reduction.

1.5.2 Methodology

The chapter details the method to determine the carbon account, the carbon footprint, for MMG, the case study mine site village. A detailed specification of the village was given followed by the setup and installation of a comprehensive monitoring system of MMGs energy and water use. A conceptual model is then developed to determine the integral parts of a carbon footprint calculation followed by a discussion of the methods adopted to reduce the footprint to zero. The calculation method of each component of the footprint is described and illustrated.

In addition to the energy and water monitoring at MMG an additional experiment was set up in the grounds of Murdoch University to study the thermal performance improvement of applying a ceramic coating to the external walls of a typical accommodation module.

1.5.3 Results

The eight research questions posited in chapter 1 are answered in detail in this chapter. MMGs carbon footprint is calculated and the processes of reduction assessed and costed to achieve a sustainable solution of how to reduce the footprint to a point of carbon neutrality.

1.5.4 Discussion

This chapter discusses: the quality, assumptions and limitations of the results and answers to the research questions; compares the thesis with previous work in the field; the application of the MMG study on as broader scale; the contribution of the thesis to research in the area.

1.5.5 Conclusions & Recommendations

The chapter systematically applies conclusions to each of the research questions followed by recommendations for further research.

Chapter 2 – Literature Review

2. LITERATURE REVIEW

2.1 Introduction

This chapter follows a logical pattern of briefly defining the broader issues of carbon accumulation in the atmosphere and the oceans: why it has had such a severe impact on life on earth in recent times; and some detail of the projections of what is likely to occur if carbon emissions are not drastically reduced immediately. The review then proceeds by way of reference to causation and international rules that have been set to limit harm, becoming more specific to the part that the built environment has to play and then more specifically to mine site village development.

Methods of carbon reduction are the subject of research in this thesis so this review covers the specifics of that analysis in the broad context of why and how this has been done in previous research. The ultimate aim of carbon neutral or low carbon settlement or mine site village development is a physical process requiring examples and discussion of how this has been achieved previously. Relevant and supporting literature sources are referred to throughout.

Global warming, climate change, greenhouse gases, and environmental impacts are discussed briefly and supported by a variety of academic sources in the literature. There is some discussion of the current trend of an unabated increase in atmospheric carbon and whether the situation is likely to improve in the near future. Fossil fuels consumption is discussed as a major source of carbon emissions and what alternatives there may be.

The significance of the global warming potential (GWP) of the construction and operation of buildings is then outlined and related to the mining industry, particularly to mine site village accommodation construction and operation. One of the main objectives of this thesis is to develop a model of how mine site villages, and similar built forms, can be constructed and operated so as to be carbon neutral, that is not adding to the global carbon account over their lifespan. There is, therefore, some explanation of ‘carbon neutrality’ in buildings, life cycle analysis, ‘carbon neutral’ and zero emission buildings. This is preceded by how the world as a whole is attempting to deal with the issue of climate change through the codification of a treaty designed to achieve this, the Kyoto Protocol. Standardization of carbon accounting rules, and guidance in applying them, is covered by International Standards (ISOs) which cover a multitude of technological and business processes. The GHG Protocol, through the aegis of the World Resources Institute (WRI, 2005), determines the GWP of any specific element, molecule or compound from all sources of human activity and how to calculate it.

The carbon footprint of a mine site village is specifically calculated in the thesis. World’s best practice, albeit limited in this specific area, is referred to along with several Australian case studies. This is followed by areas where carbon emissions can be reduced to be the most effective in its carbon footprint: thermal performance, energy efficiency and behaviour change, materials of construction and village design, smart systems and the smart camp, renewable energy systems and carbon offset mechanisms.

2.2 Climate change, global warming, GHGs and environmental impacts

In terms of Climate Change the build-up of Greenhouse Gases (GHGs) in the atmosphere from human activity is regarded as being the predominant cause (IPCC, 2013). Other gases and particulates contribute to the aggregation of GHGs but it is the preponderance of carbon molecules that is causing the majority of the warming of the planet. This carbon exists in the form of several different carbon molecules, the majority being carbon dioxide (CO_2) and methane (CH_4) from stationary energy production and the burning of transport fuels, plus CH_4 from livestock and fugitive CH_4 emissions from decaying landfill. The Kyoto Protocol lists six greenhouse gases - CO_2, CH_4, nitrous oxide (N_2O), hydro-fluorocarbons (HFCs), per-fluorocarbons (PFCs) and sulphur hexafluoride (SF_6), the latter emanating mainly from industrial processes. All molecules are converted to their carbon dioxide equivalent ($CO_{2\text{-}e}$) of GWP, as set down in the Greenhouse Gas Protocol (WRI, 2010).

Over the last forty years much has been written about climate change, its causes, methods of mitigation and adaptation, and alternative solutions. The International Panel on Climate Change (IPCC) was formed in 1988 to assess the environmental and social impacts of climate change and to develop strategies in response. The 1990 Report concluded that "continued accumulation of anthropogenic greenhouse gases in the atmosphere was likely to lead to measureable climate change." The report also introduced the concept of the GWP of a variety of greenhouse gases so that they could be directly compared (IPCC, 1990) both by the gases themselves and derivatives from their breakdown. The 1992 report further added the GWP of the depletion of stratospheric ozone and aerosols from anthropogenic emissions. These reports and subsequent issues, without exception, all confirm the urgency for drastic action to reduce GHGs.

The impacts of climate change are all too apparent: rising sea levels, increased storm surge, increased frequency of destructive and variable weather events, species extinction, biodiversity and habitat loss, health impacts, drought, soil degradation, and consequential social change. These are all manifestations of the reality that faces life on earth in all its forms and many of the tipping points, beyond which reversal is now virtually impossible, are being reached, for example: land ice melt in Greenland and Antarctica which will significantly increase sea level rise, permafrost melt which will release vast volumes of ancient stored methane to the atmosphere.

2.3 The sources of atmospheric carbon and the carbon cycle

The sources of emissions that remain within the atmosphere that cause global warming and consequential climate change are illustrated in figure 2.3 below.

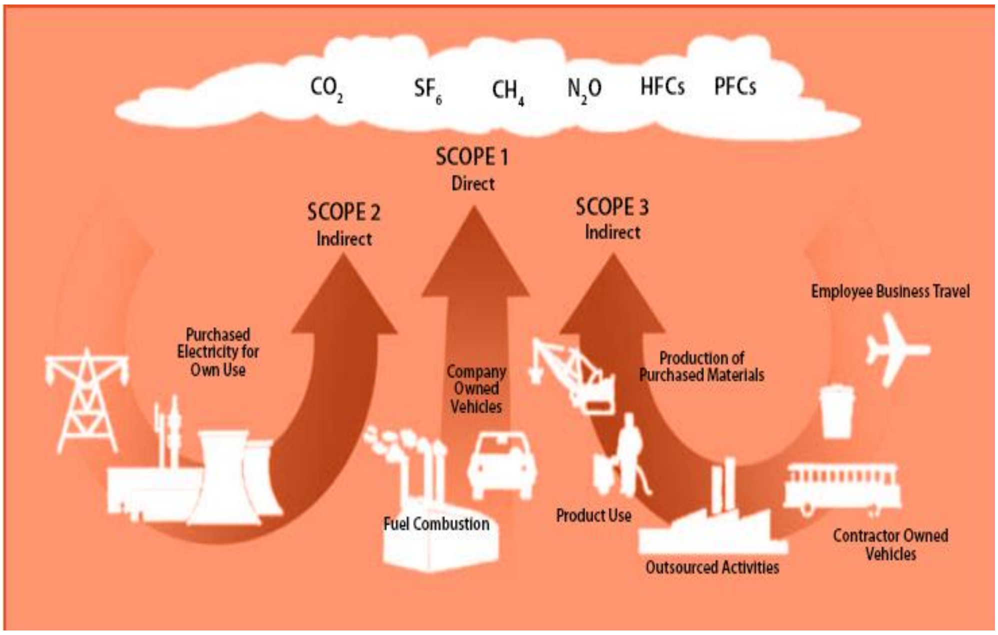


Figure 2.3: Scopes of carbon emissions in NGERS (Australia)

(GHG Protocol WRI, 2010)

Emission scopes

The scopes of emissions in figure 2.3 are outlined in the National Greenhouse and Energy Reporting System known as NGERS (DIICCSRT, 2013). They can briefly be described as GHG emissions released into the atmosphere from three principal sources:

Scope 1 – as a direct result of an activity that constitutes the facility.

Scope 2 – as a result of activities that consume electricity, heat or steam at the facility.

Scope 3 – from activities that occur outside the boundary of a facility as a result of activities at the facility.

The primary sources of atmospheric carbon are best illustrated by viewing the full carbon cycle (see Appendix 1 for the full carbon cycle). The carbon exchange between land, atmosphere and oceans can be seen in Figure 55 in Appendix 1 together with the extensive explanation the IPCC add to the schematic. Carbon remains in an inert form on land until released to the atmosphere in the form of various carbon molecules, primarily carbon dioxide (CO_2) and methane (CH_4). The CO_2 exhibits its GWP until fixed once more by plant photosynthesis or absorbed by the oceans. The majority of the CH_4 remains in various forms within the atmosphere and higher altitudes where it exhibits its own GWP. Large volumes of CH_4 are stored in natural reservoirs at the bottom of the oceans and in the permafrost in the form of carbon hydrates, and as gas reserves under the sea and land in the form of natural gas (IPCC, 2013: 471). The latter is being released in ever increasing quantities as the global thirst for cheaper fossil fuels burgeons. As for the natural stores of carbon hydrates in permafrost, as global temperatures rise, the faster the acceleration of its melting and the huge potential release of methane to the atmosphere.

The environmental award winning Carbon Tracker Institute "Carbon Bubble" report (Carbontracker Initiative, 2013: 6), highlighting the work of the Potsdam Institute in Europe, tells us that the earth's carbon budget has certain limits if global warming is to be kept at 2^{o}C or less by 2050. However, at current rates we are on course to consume internationally declared reserves of fossil fuel in the ground by year 2028. Esteemed author Warwick J McKibbin from ANU Australia and the Brookings Institution, USA is quoted:

> "The fossil fuel companies and state owners have five times as much carbon in their reserves as the most conservative government on Earth says would be safe to burn. Once you understand that, then you understand that this has become a rogue industry. This formerly socially useful thing is now the greatest threat the planet has ever faced."
>
> (Green, 2013)

The mining industry is responsible for about 5 percent of total energy consumption in Australia (ABS, 2012), the majority of which comes from the burning of fossil fuels with its consequential GHG emissions. Case studies indicate that mine site villages consume between 2 and 7 percent of mine site energy production (Anda *et al.*, 2007. Anda *et al.*, 2008.

Goodfield *et al.*, 2011). It follows, therefore, that across the mining industry as a whole, that energy efficiency measures and substitution of energy from fossil fuels can have a substantial impact in GHG emissions. In Australia the Energy Efficiency Act, 2006 was repealed recently along with much of the clean energy legislation, however NGERS still remains in force at the very least to ensure that industry keep reporting its emissions above the limits set. The market based Emissions Reduction Fund is now regarded by the Australian Government as an adequate substitute for the earlier carbon reduction legislation but there is considerable conjecture as to whether it will or not.

The IPCC predominantly lays the liability for the increase in atmospheric carbon at the combustion of 'fossil fuels from geological reservoirs......causing an unprecedented [and] major perturbation in the carbon cycle.' (IPCC, 2013: 470). Humans have brought this increase about since the beginning of the Industrial Era and continue to do so at ever increasing rates. Cement manufacture is also regarded as one of the major anthropocentric contributors to the increase in atmospheric carbon and is reflected in the 30 percent of world building industry's energy consumption referred to earlier. Changes in land use, predominantly from deforestation have also had a significant contribution (*ibid at* 474).

2.4 Industrial, anthropocentric causes of warming and tipping points.

There is a substantial and consistently growing body of scientific and academic literature concerned with GHG emissions, their accumulation, sequestration and their consequential outcomes, particularly as far as climate change is concerned. This literature varies from the peak watchdog on such issues, the IPCC, to economic reviews by the likes of Lord Stern in the UK in *The Economics of Climate Change: Stern Review* (Stern, 2006) and Professor Garnaut in the *Garnaut Climate Change Review* (Garnaut, 2008) in Australia as previously referred to. For public consumption Al Gore is well known for his book *An Inconvenient Truth* (Gore, 2006) and his award winning film of the same name. Gore followed up with a second book, Our *Choice: A Plan to Solve the Climate Crisis* (Gore, 2009). Eminent environmentalist Lester Brown has written extensively on the subject in regularly updated versions of his *'Plan B'* up to *'Plan B 4.0: Mobilizing to Save Civilization* ' (Brown, 2009). Tim Flannery, Chief Commissioner of the Australian Climate Commission and co-founder of the Climate Council, in the 'The Weather Makers' (Flannery, 2005) and subsequent titles exposes the issues and graphically exposes regretable human failing in dealing with them. All of these authors restate the fact that 97 percent of scientific commentary supports the proposition that climate change and global warming is caused by human activity and that there is an inexorable move towards the effects becoming irreversible. In answer to the sceptics' claim that the majority of atmospheric CO_2 is produced by natural means, Professor Ross Garnaut when debating the point on ABC TV, Lateline, 3rd April 2014, emphasised that the natural balance of carbon emissions had remained stable for millions of years and it was human intervention after the industrial revolution that had brought about the imbalance and rapid increase in atmospheric carbon concentration.

In a public presentation to summarize Plan B 4.0 Lester Brown refers to several 'tipping points' beyond which the severest of effects of climate change will be felt across the planet, namely: rising food insecurity resulting in political instability; the deforestation of the Amazon rainforest; loss of Greenland and West Antarctic land ice; and the rise of carbon emissions. Brown expands thus:

> *i.* *We are in a race between political tipping points and natural tipping points. Can we cut carbon emissions fast enough to save the Greenland ice sheet and avoid the resulting rise in sea level?*
>
> *ii.* *Can we close coal-fired power plants fast enough to save the glaciers in the Himalayas and on the Tibetan Plateau, the ice melt of which sustains the major rivers and irrigation systems of Asia during the dry season?*

iii. *Can we stabilize population by reducing fertility before nature takes over and stabilizes our numbers by raising mortality?*

(Brown, 2009: xii & 243)

2.5 Trends, indicators of, and exacerbation of global warming.

The British Petroleum Statistical Review of Global Energy (BP, 2012:1) states that fossil fuels currently produce 87 percent of global energy production, with oil at 33 percent, and are the main source of primary energy production. Renewable energy steadily increases its share at around 2 percent each year and the trend is for energy consumption to increase at around 2.5 per cent per annum. Coal consumption increases steadily in this sector with its consequential rise in carbon emissions and global warming potential. China is responsible for some 71 per cent of the increase in fossil fuel consumption followed by other developing countries such as India and there appears to be little abatement in this trend as these nations develop their economies. However, it must be recognised that even though China still has an enormous thirst for energy, in spite of declining growth in recent times, it continues to improve its environmental performance by installing more renewable energy, funding more environmental engineering research and planting more trees each year than any other nation.

2.6 International Agreements in Respect of Atmospheric Carbon Reduction

The Kyoto Protocol, created under the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 in Kyoto, Japan, is referred to in Chapter 1. Australia was a signatory to the Treaty but did not ratify until the Rudd Labor Government in 2008. The first commitment period of the Treaty (to 2012) aimed at reducing the carbon emissions of 37 industrialized nations by 5% of 1990 levels by the year 2012. A second commitment period was agreed in the UNFCC meeting in Durban, South Africa in 2011 to extend the Protocol for the engaged nations, which included Australia, to reduce GHG emissions by 18% between 2013 and 2020 (UNFCCC, 2012).

The Protocol, apart from setting GHG reduction targets allows nations to meet their targets by using three market-based mechanisms:

(i) *International emissions trading*: a certain number of emission units are permitted to signatory nations per annum and any of these that remain unused can be traded on the international market.

(ii) *Clean Development Mechanisms (CDMs):* which permit countries with emission reduction targets and emission limitation commitment to develop projects in developing nations to earn certified emission reduction credits, each unit being equivalent to 1 tonne $CO_{2\text{-}e}$, to count towards their emissions target reduction.

(iii) Joint implementation: similar to CDMs but as a joint venture in an industrialised nation similarly committed under Kyoto. (UNFCCC, 2013)

A new climate agreement is at the top of the agenda at COP21 summit in Paris in December 2015, where the UNFCCC convene. All developed economies have been asked to submit their policy on carbon emissions before the conference to state their "intended national determined contributions" (INDC) for reduction targets from 2020 to 2030 based on a date of previously declared levels. Australia's declared INDC is 26 -28 percent per annum based on 2005 levels, regarded by many observers as being woefully inadequate by comparison with other industrialised and several developing nations. Peak body World Resources Institute have recently published the headline "Australia offers Lacklustre 2030 Climate Target," – a condemning criticism coming from leaders in climate change policy (WRI, 2015).

2.7 'Carbon Neutral'

Carbon neutrality has become an aim for individuals, SMEs, local authorities and corporations alike whilst addressing climate change on a voluntary basis. However, many claims have been made which are unaccredited and cannot be substantiated. The resulting 'greenwash' has been used to discredit those who are justified in their claims. The

Commonwealth Government, Department of the Environment, 'Greenhouse Friendly' initiative ran from 2001 to 2010 to provide a regulated vehicle for the 'market[ing] of carbon neutral products and services, deliver [GHG] abatement, and give Australian consumers greater purchasing choice.' (DCC, 2011).The program was superseded by the National Carbon Offset Standard (DoE, 2013).

2.7.1 'Carbon Neutral' Definition

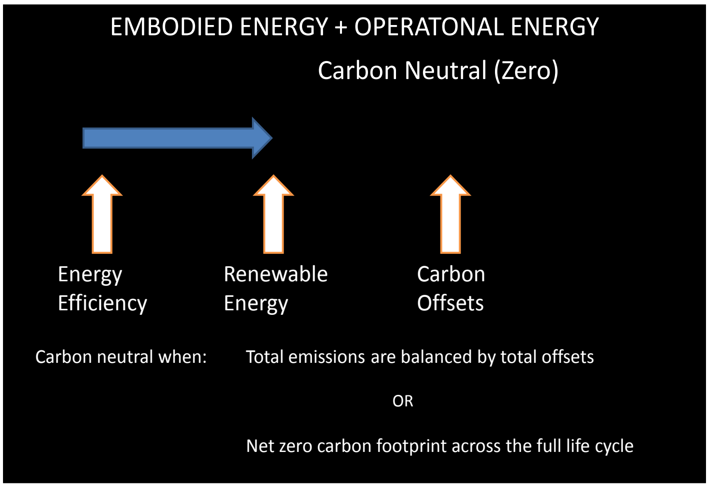
The term, like that of 'sustainability' is difficult to define precisely. Several commentators on the subject state that there is no accepted definition of this most broadly used term whether it is used in describing the carbon emissions of processes, systems, and products alike. The absence of a single acceptable international definition (Marszal *et al*, 2011) is clear from the number of synonyms for the term, including 'carbon neutral; zero energy; zero carbon; zero energy; and energy positive buildings' (ASBEC, 2011), as well as 'zero net energy; near-zero energy; climate neutral; climate positive; passive house; energy plus; fossil fuel free; 100% renewable, to name but a few (*ibid* at 3).

The term has been loosely described in section 1.2 of the National Carbon Offset Standard (2010) that:

> *To be carbon neutral commonly means that the net emissions associated with a product or an organisation's activities are equal to zero. For an organisation or product to become carbon neutral, it is generally accepted as best practice that an organisation would:*
>
> *(i) measure its carbon footprint;*
> *(ii) reduce emissions; and*
> *(iii) offset any residual emissions.*
>
> (DCC&EE, 2010:7)

This definition can be loosely represented by figure 2.4 below.

Even within scientific literature the academic definitions are few and varied, despite a raft of papers on life cycle analysis, input and output methods and tools for carbon accounting. This is particularly the case when considering which emissions of the built form life cycle are actually to be included (Wiedmann and Minx, 2008). The term ‘carbon neutral' has been defined largely by popular usage in the past (Murray and Dey, 2007: 7) with discussion of the terms ‘carbon neutral’ and ‘carbon footprint’ with several references on the subject. One such, Wiedmann and Minx (2008) concludes that a carbon footprint should only include CO_2 and no other GHGs from indirect, upstream emissions, as well as direct on site emissions. In contrast, and in the context of the thesis, the calculation of the footprint is regarded as comprising of all the carbon emissions from the complete life cycle of the MMG, the case study mine site village, that can reasonably be calculated, excluding clearing the site for development and site remediation following demolition. Determining which emissions can reasonably be included and how they are calculated will determine the potential applicability of the model to mine site village development generally (Goodfield *et al*, 2011).



EMBODIED ENERGY + OPERATONAL ENERGY

Carbon Neutral (Zero)

Energy Efficiency

Renewable Energy

Carbon Offsets

Carbon neutral when: Total emissions are balanced by total offsets

OR

Net zero carbon footprint across the full life cycle

Figure 2.4: Carbon neutral calculation – presentation slide

In 2007 the UK announced that new urban land development should be carbon neutral by 2016 and London established guidelines for carbon neutral development projects (UN-Habitat, 2011). As recently in Australia the UK Conservative government has relaxed the building codes designed to reduce carbon emissions. Malmo in Sweden claims to have the world's first carbon neutral neighbourhood and for the city itself to be carbon neutral by 2030 (National Geographic, 2012). Treasure Island in San Francisco aims to be the first US example of carbon neutral land development (Went et al, 2008). Decarbonising cities and regions is also on the agenda in Australia with progressive land developers seeking to be the first to demonstrate it, but on a voluntary and not prescriptive basis.

2.8 Life Cycle Analysis

In order to determine the carbon emissions associated with a building or community, it is necessary to ensure the embodied and operating emissions are both measured by an appropriate method of calculation. It is imperative that the method allows for comparability across a range of buildings and settlement types. International Standards apply to such carbon accounting, specifically ISO 14040:2006 together with ISO 14044:2006 and the carbon standard in ISO/TS 14067:2013. These cover the standard international methods for life cycle analysis to which any carbon account must refer in order to be compliant. PAS 2050:2011, revised in 2011 (Publicly Available Specification), is a standard for carbon foot-printing products based on ISO 14040 to ascertain the life cycle of greenhouse gas emissions of goods and services.

Carbon emission calculations are conducted by a lifecycle analysis (LCA) method (as they are for a wide range of products and services). The analysis is supported by the International Energy Agency as a valuable methodology for examining the carbon intensity of settlement development and the special assessment needs, such as the adaptability of buildings and the recyclability of materials. ISO 14040:2006, Environmental Management-

Life cycle assessment - principles and framework, outlines the requirements and process for undertaking a lifecycle impact assessment. It states that the assessment is conducted for impacts throughout a product's life, or "cradle to grave", including raw material acquisition, through production, use and disposal (ISO14040:2006).

Various approaches to life cycle analysis can be adopted. If systems, products, or services are to be compared then the mode of calculation should be comparable and the boundaries clearly defined. De Vries (2012: 448) in *Sustainability Science* emphasizes that the system boundaries ‘should be carefully specified in order to avoid confusion about and misinterpretation of the outcomes’. Four such boundary descriptions are relevant to this thesis, namely: cradle to grave, to include the raw materials of a product, its emissions throughout manufacture, use and disposal; cradle to gate, to include the materials of manufacture to a point of delivery for use; gate to gate, essentially for transport of a product from supplier to end user or consumer; and finally, cradle to cradle, an extension of cradle to grave whereby the product is recycled instead of being disposed.

Carbon Profiling, as a modification of LCA, can be applied to individual buildings or to precincts and settlements. The method develops a metric that includes the energy associated with land development, such as embodied energy in existing buildings on site and highlights the importance of the lifespan of linked components within the building system. However, this method proposes that end-of-life aspects not be incorporated as they are generally not decided at the time of construction, but could be incorporated if the site is redeveloped in the future. Compiling a carbon profile is a two-stage process:

> 1) *Calculating the operational emissions of the built form;*
> 2) *Calculating the embodied energy of the buildings and associated infrastructure.*
>
> (Sturgis & Roberts 2010: 20)

2.8.1 ‘Carbon Neutral’ and ‘Low Carbon’ Buildings

Due to the inclusive nature of the LCA the carbon accounting process requires that a variety of tools need to be employed to make an accurate assessment of the embodied and operational energy of the urban form being analysed. Operational energy is particularly difficult to calculate as from activities, essential to accessing and running any urban form, will likely occur from scope 3 emission sources ‘not owned or controlled’ by the operators, (ACCC, 2008:13) Examples are the delivery of food and groceries and air travel access. A mining entity is not required to account for scope 3 emissions but they can be included in an LCA with an appropriate declaration to show the extension of the boundary of inclusion in the analysis. The rationale for this is that essential services to keep an urban form operating can be considered as part of the operational energy even though it is not responsible for the emissions when it comes to compliance with carbon emission declaration legislation (NGERS).

The total value of emissions attributable to an urban form will likely influence any subsequent reduction strategy. The strategy can be modified according to the needs of the various stakeholders: the building manufacturer; and in the case of a mine site village, the infrastructure developer, the village owner and its operator. The solutions will likely fall into several categories, namely: modification of the current power generation plant; energy efficiency opportunities; renewable and sustainable energy options; and the purchase of appropriate accredited offset mechanisms. As regards offset mechanisms the ACCC is particularly concerned about the selling of these offsets, partly due to the management of such sales often resulting in multiple trades of the same offset, and to the inaccurate accounting of the carbon reducing value of the offset itself.

Once the overall footprint of the village is calculated, following the NCOS guidelines referred to earlier then the task of building a reduction strategy can commence. This could include: reduction of the embodied energy of construction; implementation of operational energy efficiency measures; renewable energy system offsets; smart control systems, and; accredited biomass and carbon offset of the remaining emissions until a point of carbon neutrality is achieved, each process measured by the mass of carbon they are reduced by.

The State of Victoria (Victoria State Government, 2015) is particularly proactive when it comes to environmental stewardship and sustainability. It has published a comprehensive booklet and website to cover developing and living a low-carbon life primarily focused on the home. The *'Your Home Technical Manual"* describes itself as *"Australia's guide to sustainable house design and construction."* The latest edition described 'carbon neutral, zero energy and carbon positive homes' and the steps required to move towards them as:

1. Calculate the amount of emissions and energy being used.
2. Reduce the demand for energy and activities that produce greenhouse gas emissions.
3. Improve energy efficiency technologies.
4. Incorporate renewable energy and use GreenPower.
5. Offset the equivalent amount of emissions in other areas and activities.

(Formerly section 1.4 of the *Your Home* Technical Guide)

The website elaborated further on the definition of the term 'carbon neutral':

> *[It] aims to balance the overall amount of* CO_2 *being emitted into the atmosphere, by calculating how much* CO_2 *is being emitted from an activity and reducing the equivalent amount of* CO_2 *in another activity.*

On a wider scale a recent publication 'Sustainability, Energy & Architecture: Case Studies in Realizing Green Buildings' (Sayigh *et al.*, 2014) gives a contemporary contrast to the *Your Home* Technical Guide. It presents a global and comprehensive, academic and practical analysis of green building with a wide variety of international case studies. It covers many facets of the design and construction of including detailed and illustrated sections on:

low carbon and zero emission buildings; low energy approaches to design; incorporation of renewable energy; green and energy efficient building in the desert climate; life cycle analysis; the LED revolution in lighting; sustainable building in the Mediterranean area; social implications of sustainable buildings and their relationships with humans and nature sustainable architecture in Africa.

2.8.2 Smart systems for building control and energy efficiency

Smart (digital) control systems have been developed over time but few have been tested in a mine site village setting. To date no mine site village has been set up to use a fully integrated smart system to operate more efficiently, particularly for village occupancy and building control. The IKS Automation and the iMCA Controller™ system (IKS: 2014) can add intelligence to any building or collection of buildings to operate motorised doors and window openings, lights, air-conditioning, motion and anything else that is monitored by sensor (see figures 2.5 & 2.6 below).

“Smart Camp” development has been investigated by both IT and sustainability academics and investigates how the implementation of smart systems can improve the operation of mine site villages and enhance the livelihood of the residents, and improve energy efficiency.

Little practical research has been done in the field to coordinate IT software and hardware developers with environmental engineers. Effective synergy between the two groups is essential for productive outcomes (Lee, K. *et al*., 2012). Our paper uses the MMG case study in this thesis to demonstrate the agile operation of Wireless Sensor Networks within the Cloud Computing infrastructure, and thus the demand-driven, collaboration-intense paradigm of Digital Ecosystems in Complex Environments (Kohn et al, 2010).

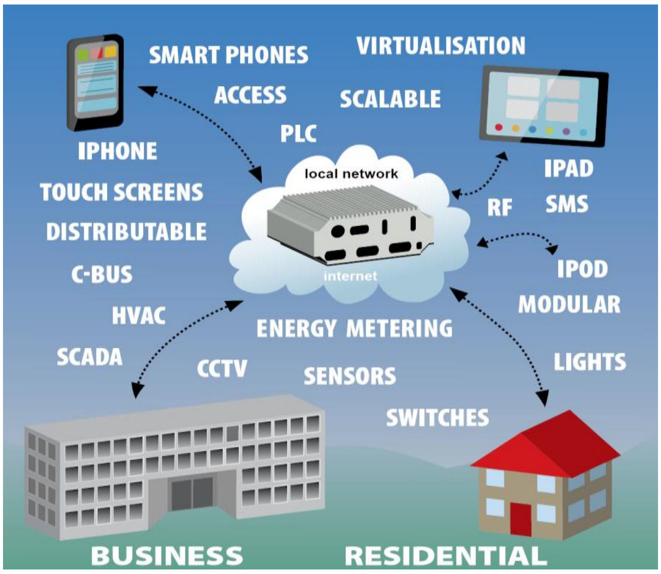


Figure 2.5: Intelligent building operation

(IKS: 2014)

Sensor Networks allow data to be collected from the physical world from a range of locations. This can include environmental data such as temperature, water consumption and waste, energy use, and any system requiring monitoring or measurement. The operation of these systems usually begins with sensors collecting data. This data is then transmitted to a gateway and from there to a back-end system for analysis.

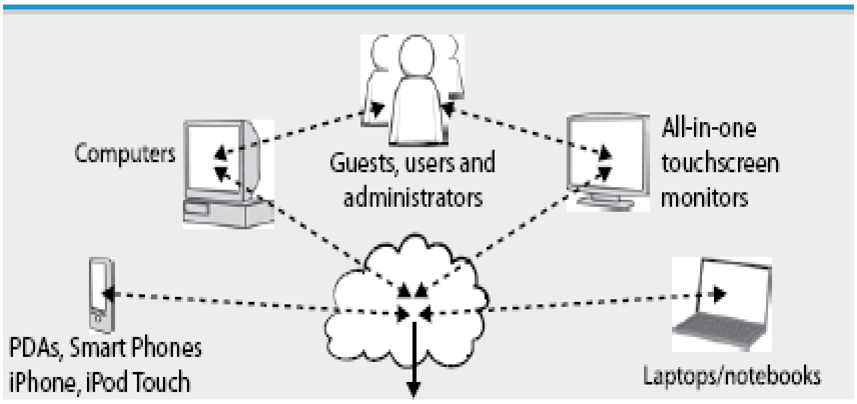


Figure 2.6: The “Cloud’ network.

(Aboudi & Talevski, 2010)

Aboudi & Talevski (2010) “proposes the use of a wireless sensor network system....to remotely control amenity functions and reduce energy consumption emissions [and] investigates environmental sustainability and improved quality of life aspects through the use of multimedia convergence technologies” to “reduce environmental impact, operational costs and improve overall amenity.” Three main areas are considered:

- Presence monitoring – where detectors signal movement,
- Access control – using RFID for security and access control, and
- Power control – of lighting, HVAC, water heating, entertainment and climate.

Kohn *et al* (2010) demonstrates the overall scenario in a simple graphic, figure 2.7:

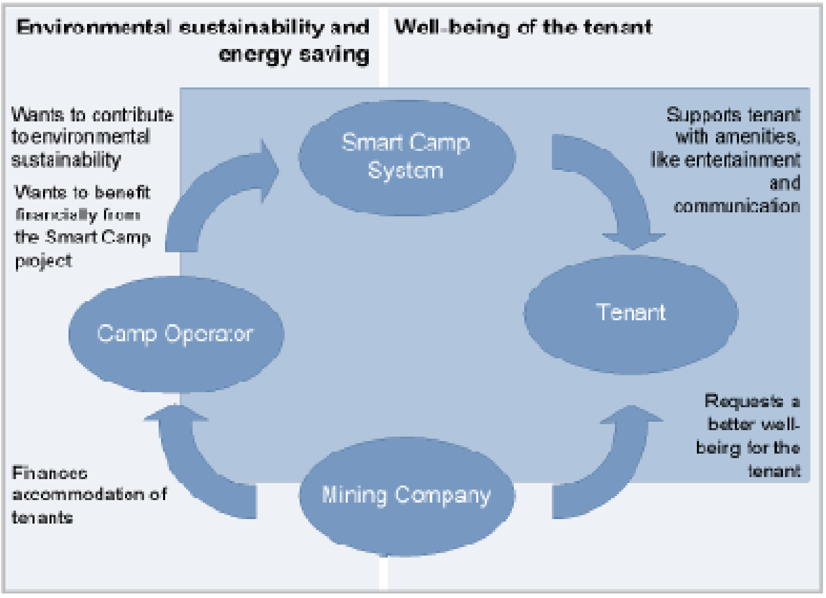


Figure 2.7: Smart system setup

(Kohn *et al.*, 2010)

Eisfield & Karduck (2012) suggest the development of two kinds of software solutions: a Smart Home Control (SHC) unit for environment control and a Smart Central Management Unit (SCMU) for the co-ordination of the SHCs. The SHC will “observe and control certain electrical devices according to requests sent by the SCMU controller sited in any chosen location. Further research papers on ‘Smart Camp Development’ include Karduck *et al.* (2012) and Oslislo *et al.* (2011).

Whatever the architecture of a smart camp system may be, and the software to drive it, little is tested in the mine site village scenario or any other collection of residential buildings. Building management systems exist in many forms in commercial buildings, but the introduction of smart systems in the space for co-ordinating multiple residences still remains largely empty. Shared facilities such as solar power or water heating certainly exist, but the smart control of multiple environments still remains a void to be filled.

2.8.3 'Zero Emission' Buildings

Zero emission and zero carbon buildings are appearing with increased frequency in the media as well as in academic papers. The ASBEC report (2011), completed for the Victorian Government, states that 'a zero carbon building is one that has no net annual scope 1 and 2 emissions from the operation of the building and incorporated services.' This means that these emissions have been calculated and offset by alternative means. The report further states that:

> - *Building-incorporated services include all energy demands or sources that are part of the building fabric at the time of delivery, such as the thermal envelope (and associated heating and cooling demand), water heater, built-in cooking appliances, fixed lighting, shared infrastructure and installed renewable energy generation.*
> - *Zero carbon buildings must meet specified standards for energy efficiency and on-site generation.*
> - *Compliance is based on modelling and/or monitoring of greenhouse gas emissions in kg* $CO_{2\text{-}e}/m^2$ *annum.*
>
> (ASBEC, 2011)

2.9 World's best practice mine site village development.

There are very few examples around the world where mine site village accommodation has been specifically designed on a low carbon and potentially sustainable model. There are some cases where sustainable improvements have been made at the time of installation or even as a retrofit (Xstrata, 2013. Glencore, 2015), but instances where sustainable design has been adopted as a holistic model do not exist. Much of mining focuses on environmental compliance, community health and physical well-being but sustainability is not part of the lexicon.

An Australian Government Report (DRET, 2011) entitled "A Guide to Leading Practice for Sustainable Development in Mining" makes no reference to the sustainability, or otherwise, of the various accommodation types and styles supporting the industry. The sustainable integrity of the built environment supporting mining is clearly relevant to the sustainability of the enterprise as a whole and should be addressed.

Hart (1997:71-73) in the Harvard Business Review set out a 3-stage approach to sustainable development and one which particularly applies to the mining industry today:

Stage 1: pollution prevention.
Stage 2: product stewardship, reduction and minimizing of environmental impacts over the life of a product.
Stage 3: clean technology, updating production techniques to move into clean technology.

Stage 3 features in mining operations but generally only when production efficiencies are the reward and not carbon emissions. Diesel and gas savings have an immediate financial benefit and until carbon emissions become costly the mining industry is unlikely to respond.

Professor Chem Nayer, founder of the Centre for Renewable Energy and Sustainable Technologies Australia at Curtin University, told *Mining News Premium* that the 120 kW hybrid RE system Regen Power Ltd had designed and installed at Eco Beach Wilderness Retreat, Broome, Western Australia, would reduce fuel cost by up to 30 percent. He added that "the system would be ideal for mining camps where energy requirements varied over the day" (Batten, 2009).

2.9.1 Australian 'low carbon' mine site villages

Australian mining companies have publicly expressed their desire to demonstrate an ethical corporate responsibility to their shareholders and to the public at large. As mining activities represent a significant source of atmospheric carbon pollution this is especially true during current times of climate change awareness. Global miners, Rio Tinto, BHP and Xtrata, all significantly represented in Australia, do accept their responsibility to tackle climate change (Rio Tinto, 2011; BHP, 2013; Xtrata, 2011). Environmental consultants Sinclair Knight Merz indicate that mining companies are now giving serious consideration to ecological sustainability in mine site accommodation development, as well as mining *per se.* They report on one such investigation (SKM 2008), however, to date little more has been published by others. The award-winning SKM report reveals no quantification of the overall carbon footprint and merely indicates a reduction in water use of 50 percent and energy use of 30 percent per head.

Robert Tromop, head of the Energy efficiency unit at the International Energy Agency, has been recently quoted saying that "global [opportunities] for building[s] energy savings are in the order of 60 percent" and emphasised the need for effective energy codes, labelling and incentive schemes, as well as the need to take an "urban systems approach" beyond buildings themselves (McKibben, 2013). This applies to mine site villages as much as any built form.

A small number of mine site village developers have pursued low-carbon and carbon neutral mine site village development. Several examples follow in section 2.9.1.1 to 2.9.1.6.

2.9.1.1 Santa Barbara, Western Australia

The Santa Barbara mine site village near Leonora, Western Australia has been transformed on the basis of the SKM report referred to above. The village was originally one of high energy and water consumption, with a typical and ordinary village landscape. This scene was transformed to a much lower emission, water efficient and conserving, pleasant looking village, as seen in contrasting photographs in figures 2.8 and 2.9.

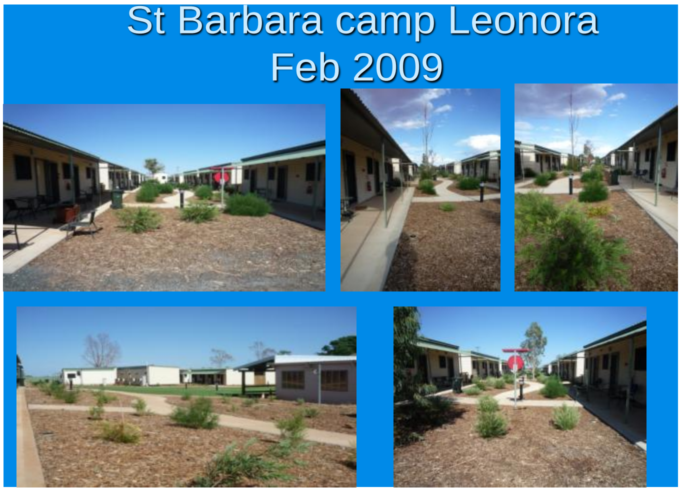


Figure 2.8: Santa Barbara Village – early days of development

Figure 2.9: Santa Barbara Village – matured after 3 years

Santa Barbara Manager of Environment & Community, Jeff Waddington, was the force behind this transformation. His work in progress was presented to the Chamber of Minerals and Energy, the peak mining body of Western Australia, and proved valuable in learning about the changes that can be made to retrofit an existing mine site village. The message given was that it is possible to transform the living conditions of a mine site village to one which benefits the workforce in terms of their living environment, and has a significantly lower environmental impact than traditional villages whilst also benefiting the mining company financially. No figures have been given out publicly to support these claims, but according to conversations held with Mr Waddington, it is clear that the effort put into the retrofit of the village has, in terms of sustainable development, been very positive. An extract from the SKM report is given below in table 2.1.

Some of the initiatives implemented included:

Initiatives	Results
Concrete floors	Reduces demand for heating and cooling
Parasol roof design and larger verandas	Absorbs and reflects heat as well as cooling air passing through to reduce cooling demand
Solar energy generation	Energy generated is fed into the switchboard and provides base-load energy requirements for the village
Greywater (GW) reuse system from all rooms. The GW is delivered to gardens	Reduces water consumption associated with gardens
Energy and water efficient washing machines	Reduces water and energy consumption
Low flow shower heads	Reduces water consumption
Upgrading of existing facilities, ie gym, recreation room, and kitchen	Reduces energy and water consumption

Table 2.1: Extract from SKM report 2011

2.9.1.2 Crosslands Jack Hills Expansion Project (JHEP), Western Australia

Due to the drop in demand for iron ore JHEP operations were suspended in 2012. However, the 2010 targets for the development of the accommodation village went a long way towards ensuring a positive change in how mine site villages were designed, constructed and operated. The village would have originally supported 2,500 workers in the mine construction phase and 1,200 during an anticipated life of 30 years. A comprehensive report was produced by Cardno (WA) Pty Ltd, an infrastructure and environmental services provider, entitled ‘Eco-village Sustainability investigation – JHEP’ submitted to the Environmental Protection Agency in support of Crossland Resource Ltd’s application to commence mining (Lisle & Sim, 2010:3). The objectives were:

> *To provide a comparative analysis of environmental alternatives in the design and construction .... with considerations of cost [in] three scenarios:*
>
> - *Business as Usual*
> - *Enhanced practice; and*
> - *Leading innovation.*

The basis for design, regarded as the ‘business as usual’ scenario was prepared by Worley Parsons Ltd to address the minimum design and engineering requirements of the village. A similar basis applies to the industry of mine site village construction as a whole – that of ‘Conventional practice.’

‘Enhanced Practice’ - ‘was considered as technology or design that.... recognised as delivering a more effective environmental and potentially a better economic outcome than [BAU].’

‘Leading Innovation’ - ‘was considered as technology or design that presents outstanding environmental benefits, whilst potentially incurring high economic costs.’

The analysis targeted six areas: energy, water, waste, natural environment, design and layout, and building materials and covered a wide area of possibilities as seen in table 2.2 below.

The Cardno report is clearly informative of the broad possibilities of how to achieve a more sustainable mine site village for their client. However, the analytical integration of the systems and technologies does not appear to justify the inclusion of them set against any pre-existing benchmarks. The report is a feasibility study without conclusion of what actions, or combination of actions, is actually feasible, especially from a financial standpoint.

Area of Investigation	Recommended for implementation
Energy	› Metering › Motion sensors › Variable Refrigerant Flow Air Conditioning › Highest star rated appliance energy ratings › Energy Smart Card System › LED Lighting › Flat panel solar or tubing water heaters › Gas Optimisation (with detailed feasibility analysis) › Wind Power (with detailed feasibility analysis)
Water	› Retention of natural vegetation › Minimise large areas of grass › Highest rated Water Efficiency Labelling Scheme (WELS) building fit out efficiencies › Rainwater tanks (with detailed feasibility analysis) › Bioswales and Bio-pockets to reduce run-off of stormwater › Use of native vegetation › Strategic use of shading and wind protection › Use of organic matter › Use of rocks and gravel for features › Greywater systems › Use of subsurface irrigation (on small scale) › Use of recycled or harvested water for garden irrigation
Waste	› Prefabricated / fully recyclable buildings › Reuse non disposable items › Landfill of residual wastes › Smart procurement and building design › Recycle packaging and food containers (operational) › Procurement of baler, glass crusher and shrink wrapper › Recover cooking oil › Reuse of oversupplied materials › Recycling of scrap metal off cuts › Recycle organics (food waste) via waste water treatment plant › Pressure of supply chain
Layout & Design	› Facilities Audit › Phasing and adaptability › Creation of distinct neighbourhoods › Clustering of complementary land uses and community / neighbourhoods › Site coverage and layout › Building setbacks

Table 2.2 Environmental initiatives to provide cost savings in short to medium term

(Lisle & Sim, 2010: 5)

2.9.1.3 Mt Cattlin, Ravensthorpe, Western Australia

Galaxy Resources' mining operations were the first in Australia to have a significant proportion of its energy generated by RE, including the mine site village. A combination of solar tracking PV (figures 2.10 & 2.11) and wind turbines were installed by Swan Energy Ltd capable of generating 226 MWh of renewable energy per annum. A 5MW diesel generator was installed as the main power source with the RE systems representing approximately 15 percent of the overall energy requirement of the operation whilst saving over 200 tonnes of fossil fuelled carbon emissions per annum. The intention was to gradually increase the RE proportion, but world resource markets dictated the eventual closure of the mine in 2013 (Burke, 2011).

Figure 2.10 Solar tracking PV array at Mt Cattlin

Figure 2.11: Wind turbines and solar tracking PV at Mt Cattlin

2.9.1.4 Sandfire Resources, Western Australia

The DeGrussa Copper-Gold Mine is programmed to become be the site of a 10.6 MW solar PV installation and set to be the largest integrated off-grid solar power system to be used in the mining industry anywhere in the world. The solar array is shown in figure 2.12

as the parallel shaded area. Once complete the solar array will offset in the region of 20 percent of the diesel fuelled generation and abate over 12,000 tonnes $CO_{2\text{-}e}$ per annum.

Figure 2.12: Aerial view of DeGrussa Copper-Gold Mine and proposed static solar array (Australian Mining News, 2015)

Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation provided both substantial finance and grants but ARENA CEO, Ivor Frischknecht, is quoted as saying:

> *"The undertaking at DeGrussa is supported by modelling showing similar projects could be viable without government subsidies in the near future."* (Australian Mining News, 2015)

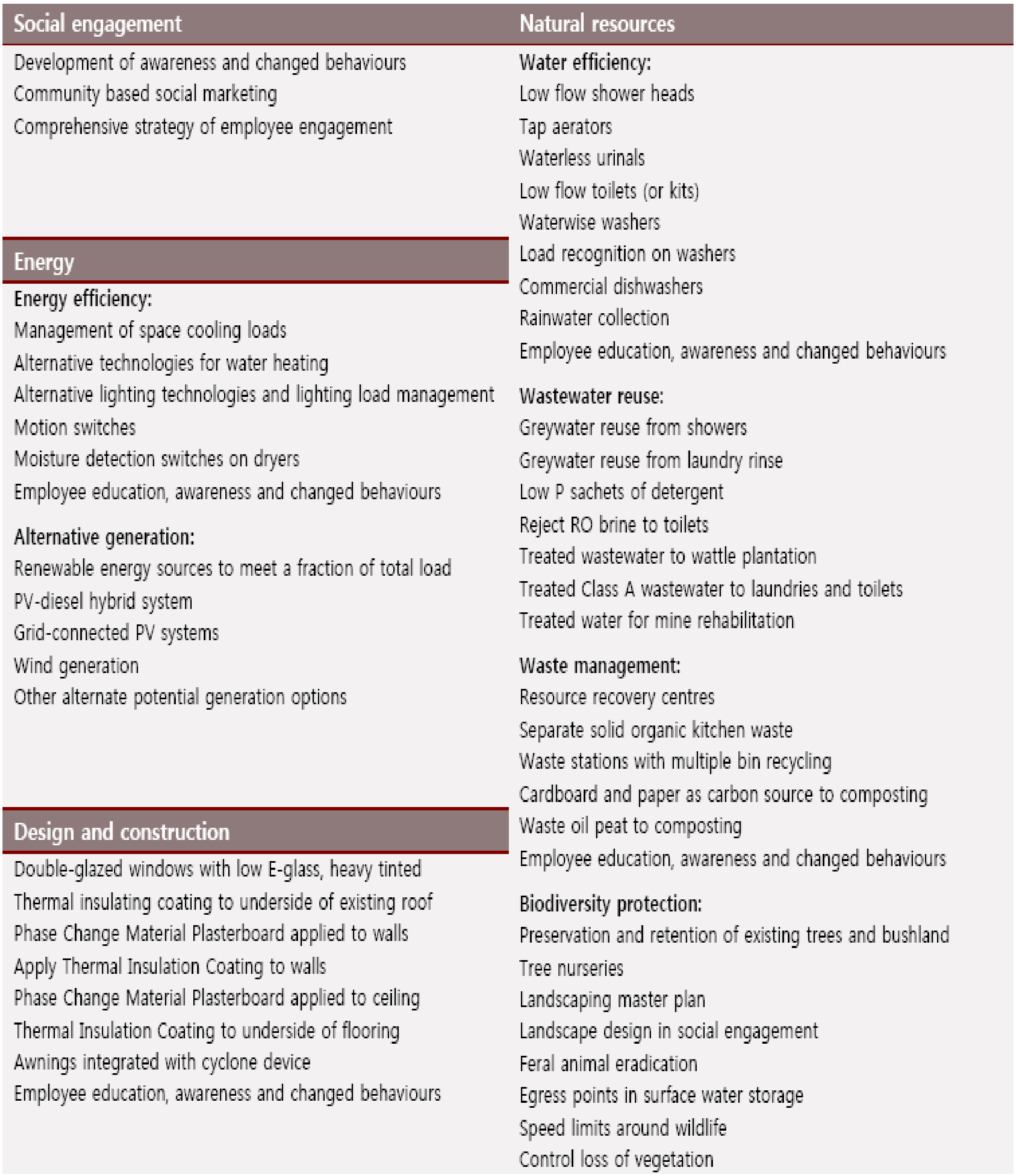
DeGrussa regional director added:

> *"The Sandfire project shows that it is economically viable to use solar power in combination with battery storage on a large scale. From a technical perspective, the project demonstrates that even a mine in the Australian outback can be safely and reliably supplied with solar power."* (Australian Mining News, 2015)

2.9.1.5 Fortescue Metal Group, Cloudbreak Village, Pilbara, Western Australia

By mid-2008 a consortium of contributors, including the writer, had completed a detailed study aimed at developing for the stakeholder, Fortescue Metals Group (FMG), entitled "Australia's First Sustainable Mine Site Village." Regrettably the global financial crisis hit the resource industry extremely hard and the project went no further. The extensive study reviewed data and best practice in the areas of social engagement: built form thermal performance and energy efficiency; camp design, layout and forms of construction;

renewable energy; natural resources; water efficiency and conservation, including wastewater reuse; solid waste management; and biodiversity protection. A summary of the options from the report extracted from the report is set out in table 2.3 and forms part of a detailed report of options and data gathering for Fortescue Metals Group (Anda *et al.*, 2008).



Social engagement

Development of awareness and changed behaviours
Community based social marketing
Comprehensive strategy of employee engagement

Energy

Energy efficiency:
Management of space cooling loads
Alternative technologies for water heating
Alternative lighting technologies and lighting load management
Motion switches
Moisture detection switches on dryers
Employee education, awareness and changed behaviours

Alternative generation:
Renewable energy sources to meet a fraction of total load
PV-diesel hybrid system
Grid-connected PV systems
Wind generation
Other alternate potential generation options

Design and construction

Double-glazed windows with low E-glass, heavy tinted
Thermal insulating coating to underside of existing roof
Phase Change Material Plasterboard applied to walls
Apply Thermal Insulation Coating to walls
Phase Change Material Plasterboard applied to ceiling
Thermal Insulation Coating to underside of flooring
Awnings integrated with cyclone device
Employee education, awareness and changed behaviours

Natural resources

Water efficiency:
Low flow shower heads
Tap aerators
Waterless urinals
Low flow toilets (or kits)
Waterwise washers
Load recognition on washers
Commercial dishwashers
Rainwater collection
Employee education, awareness and changed behaviours

Wastewater reuse:
Greywater reuse from showers
Greywater reuse from laundry rinse
Low P sachets of detergent
Reject RO brine to toilets
Treated wastewater to wattle plantation
Treated Class A wastewater to laundries and toilets
Treated water for mine rehabilitation

Waste management:
Resource recovery centres
Separate solid organic kitchen waste
Waste stations with multiple bin recycling
Cardboard and paper as carbon source to composting
Waste oil peat to composting
Employee education, awareness and changed behaviours

Biodiversity protection:
Preservation and retention of existing trees and bushland
Tree nurseries
Landscaping master plan
Landscape design in social engagement
Feral animal eradication
Egress points in surface water storage
Speed limits around wildlife
Control loss of vegetation

Table 2.3: Options identified for a sustainable mine site village (Anda *et al*., 2008: ii)

2.9.1.6 Rio Tinto Iron Ore, Mesa A construction Camp, Pilbara, Western Australia.

A team of researchers and industry experts compiled a report for Rio Tinto Iron Ore (RTIO) similar to the FMG report in section 2.9.1.4. In brief the project aimed at providing RTIO with the following outcomes (Anda, *et al.*, 2007):

1. Innovations on sustainable mine site accommodation that will inform future design work at camp or village scale;
2. The maximising of energy efficiency in camp accommodation modules;
3. The minimisation of water use in camp accommodation modules; and
4. The investigation of the potential for alternative energy generation and its inclusion where feasible.

2.9.2 Calculation of emissions at the precinct level

The carbon reduction process in the built environment has moved well beyond the analysis of individual buildings for compliance purposes to understanding the significance of the built forms' carbon intensity on a broader scale, the precinct level. A precinct could be merely a small group of buildings to a subdivision that has common infrastructure and services – the larger it is the more complex the carbon footprint calculation and solutions become. A number of software tools have been developed globally to analyse precinct development in order to plan and construct them on a more sustainable level. Due to the disparate nature of precinct development the basic framework, function and scope of these is wide and varied - including rating tools, checklists, performance tools and inventory life cycle analysis, as well as hybrids thereof. The scope of assessment they present determines the tool selected as being fit for purpose. Few are capable of measuring carbon emissions directly as the focus of them is predominantly upon design of precincts rather than carbon intensity and carbon accounting. The result of improved sustainability will certainly reduce the carbon footprint but the majority of the available Australian and international tools are incapable of determining this reduction quantitatively. An industry group, led by UNEP's

Sustainable Buildings and Climate Change Initiative (UNEP, 2009) recognises this shortcoming and in recent years has been developing a universal tool, the Common Carbon Metric, to address the issue of carbon measurement in buildings but still largely focuses on measuring energy efficiency improvements.

There are two tools available in Australia which possess a quantitative element to a precinct's carbon emission assessment and its reduction: CCAP Precinct (known as PRECINX™) and eTool™.

PRECINX: Draw[s] on comprehensive local data sources including climate and utility data, it links urban design with environmental metrics to calculate the performance of a development across transport and land–use, embodied energy, operational energy, water and stormwater, housing affordability, capital and recurrent costs and household operating costs. (Kinesis, 2009).

eTool: Building life cycle assessment tool to calculate and analyse a building's embodied energy, and to facilitate reduction (eTool, 2015)

With the odd exception the available case studies reveal cursory attention to the overall problem of carbon emission reduction as a primary objective in mine site village development. A small number of mining enterprises are turning towards RE to supplement a proportion of the fossil fuels used in generating their overall energy needs with the residential village attached by a spur line. Individual systems and technologies are incorporated in current villages but the decision to do so are based solely upon convenience and cost with little or no regard to the wider benefits. The incorporation of energy-saving devices such as solar and heat pump hot-water systems, and RE producing wind turbines and photovoltaic panels, have all been incorporated to some extent in various combinations in many camps now in operation. It still remains for a village to be designed by incorporating sustainability principles from the outset.

2.10 Conclusion

The increasing concentration of atmospheric carbon emissions is predominantly accepted as being induced by humans. The effects of this steady increase are regarded as being responsible for global warming and on climate change and its serious consequences. However, there is a constant debate between those who accept this proposition and those who don’t. The argument revolves essentially around whether the effort to mitigate the steady increase in GHGs, and the concomitant cost of doing so, has an acceptable degree of impact, or whether the time, effort and money is better spent in adapting to the inevitable. The literature in this chapter supports the former view and that many tipping points of irreversible change are upon us. A global agreement to enforce dramatic GHG reduction over the next 15 years is anticipated in late 2015 at COP21 in Paris, but a positive resolution is by no means certain given the disparate views on the issues and alternative agendas.

The production of energy using fossil fuels is regarded globally as a major contributor to the increase of GHGs and the literature confirms that around 40 percent is consumed by the construction and operation of buildings producing 30 percent of global carbon emissions. Decarbonisation of the built form could therefore produce a substantial reduction. The thesis focuses on the decarbonisation of cities and regions, and concentrates upon mine site village and similar precinct development.

The literature reveals that there has been little work done in respect of carbon reduction in mine site villages and like precincts as a whole. The majority of approaches focus on cost saving leaving the social and environmental paradigms of sustainable development relatively ignored – bottom line approach avoiding the triple bottom line.

Individual building energy efficiency is assessed individually using a variety of rating tools, such as NABERS, and associated tools such as BERS Pro, FirstRate, and AccuRate in

Australia, BREEAM in the UK and LEED in the US, all of which ensure that buildings conform to regulation. The standard to which a building becomes more energy efficient depends on the rating tool used – in Australia the energy tools set a standard which is often criticised as setting the benchmark too low. Furthermore, constructing energy efficient buildings does not necessarily mean that they will be operated to their potential as this would depend on the occupiers. However, low carbon construction, reducing buildings' embodied energy has shown to have the potential to reduce their carbon footprint substantially.

Global miners, Rio Tinto, BHP and Xtrata, all significantly represented in Australia, accept their responsibility to tackle climate change. Most Australian mining companies have openly and publicly expressed their desire to demonstrate their ethical corporate responsibility, especially with regards to their environmental impact and, in these times of climate change awareness, the carbon pollution they are responsible for. However, words are not necessarily put into action. Australian Ethical Investment Ltd (AEI), referred to in Chapter 2, say that this is perhaps pushing the *modus operandus* of the mining companies too far, but dealing with their carbon pollution is certainly on their agenda.

Environmental consultants Sinclair Knight Merz (SKM, 2008) indicate that mining companies have recently given serious consideration to ecological sustainability in mine site accommodation development, as well as mining *per se*, and report on one such investigation. Little more has been published by others on the subject although RE production at mine site level is certainly on the increase as the cost of fossil fuels increases. This thesis is much more informative in terms of how to develop a model for carbon footprint calculations and how to calculate a specific mine site villages' carbon footprint as a whole. This is extended to the determination of sustainable methods of carbon reduction to a point where carbon neutrality can be legitimately claimed. Greater attention to alternative design and systems to operate mine site villages could prove not only environmentally beneficial but financially viable, especially fulfilling the need to understand the potential of RE systems to supplement conventional power production. Furthermore, these benefits could well translate into improvements in precincts built on similar lines to the mine site village, such as retirement villages, holiday complexes, and the like.

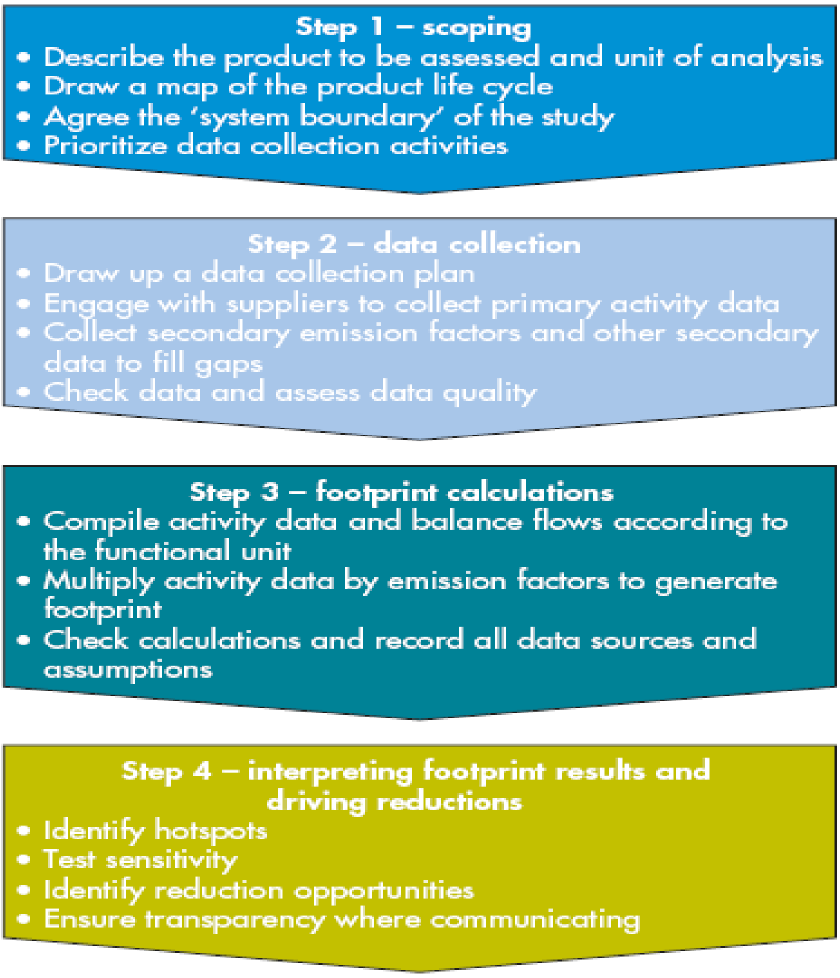
Chapter 3 – Methodology

3. METHODOLOGY

3.1 Introduction

The most widely used and globally accepted standard for GHG emission accounting, the Greenhouse Gas Protocol, was developed by the World Resources Institute and the World Business Council for Sustainable Development, and provides the accounting framework for governments and business for almost all GHG standards and programs.

The carbon accounting standards referred to in Chapter 2 were adhered to, particularly as public claims may be made of the results. The process in Standard PAS2050 simplifies description of the method of accounting followed in the thesis, as set out in figure 3.13:



Step 1 – scoping

- Describe the product to be assessed and unit of analysis
- Draw a map of the product life cycle
- Agree the 'system boundary' of the study
- Prioritize data collection activities

Step 2 – data collection

- Draw up a data collection plan
- Engage with suppliers to collect primary activity data
- Collect secondary emission factors and other secondary data to fill gaps
- Check data and assess data quality

Step 3 – footprint calculations

- Compile activity data and balance flows according to the functional unit
- Multiply activity data by emission factors to generate footprint
- Check calculations and record all data sources and assumptions

Step 4 – interpreting footprint results and driving reductions

- Identify hotspots
- Test sensitivity
- Identify reduction opportunities
- Ensure transparency where communicating

Figure 3.13: Extract from Standard PAS2050

Mining companies are particularly sensitive to market forces, especially in Australia where the margins for profitable returns are ‘cut to the quick.’ Mine site villages constructed to support mining exploration and resource recovery are subject to similar budgetary constraints. Predicting the life span of a village accurately is difficult as premature closure of mines is frequent. The lifespan of MMG, the case study central to the thesis has, therefore, no definitive lifespan so periods of 5, 10, 15, and 20 years were used as reference points.

The carbon accounting method described requires that a variety of tools be employed to make an accurate calculation of embodied and overall operational energy of the case study village. Some elements of MMG’s operation are particularly difficult to calculate as several activities essential to accessing and running the village occur ‘from sources not owned or controlled’ (ACCC, 2011: 10) by the village operators.

The overall emissions attributable to the village will influence any strategy for reduction varying according to the needs of the many stakeholders involved: the building manufacturer, village infrastructure developer; village owner and operator; and, the resident workforce. The solutions for emission reduction will fall into several categories, namely: modification of the current power generation plant; energy efficiency opportunities and behaviour change programmes; renewable and sustainable energy options; and the purchase of appropriate accredited offset mechanisms. The ACCC is particularly concerned about the selling of offsets, partly due to the management of such sales often resulting in several trades of the same offset, and to the inaccurate accounting of the carbon reducing value of the offset itself.

Having established the overall footprint of the village, by following the National Carbon Offset Standard (DoE:2013b) guidelines and LCA standards, the task of carbon reduction follows with the aim of reaching a carbon account that can legitimately be described as ‘carbon neutral.’ This includes: reduction of the embodied energy of construction; implementation of operational energy efficiency measures and personnel behaviour change education; renewable energy system offsets; and accredited carbon offset purchases for the remaining emissions until a point of carbon neutrality is achieved, each process being measured by the mass of carbon they are reduced by.

One of the principal aims of the thesis is to develop a sustainable and credible GHG accounting model to reduce the carbon footprint of a mine site village to a point of carbon neutrality as per the description of ‘carbon neutrality’ in chapter 2 and by following government guidelines (DoE: 2013c) The MMG case study provides a comprehensive way in which to achieve this including an additional experiment to field test a ceramic coating applied to accommodation modules similar to those used universally as the major built form in mine site villages and the like.

3.1.1 Developing the conceptual model

The aim of this section is to describe the development of a conceptual model upon which the research was founded, as drawn in figure 3.14 below.

The research program as a whole has been structured to define a carbon reduction strategy for mine site village development that will inform village designers, constructors, operators and owners how they can legitimately claim carbon neutrality and provide a template for future village development. Two main inputs comprise the carbon footprint of the village as a whole: the embodied energy of the built form and associated infrastructure and operational energy consumed to run the enterprise. The energy required for removal and site remediation does not form part of the LCA as mentioned earlier in section 2.7.1. Table 3.4 sets out the order of research.

	Line of Research	Method/Composition	Comments
1	Preliminary investigation	Review of design drawings	
2	Site visit, monitoring equipment deployment & data collection		
i	Collect data from primary power circuits and water meters	Deploy sensors, data loggers for 24/7 online data collection	3 years' data collected (at time of writing)
ii	Determine overall & individual peak power loads	Data analysis	Checked with company metering at mine generation plant.
iii	Determine overall & individual circuit energy use.	Data analysis	
3	Carbon accounting		
iv	Determine full carbon account over various life-spans of village.	Section 3.1.2 & 3.1.3	5, 10, 15, & 20 years
v	Determine annual carbon account for various life spans of village.		
vi	Assessment of carbon emission reduction using energy efficiencies and behaviour change.	Section 3.4	
4	Technology Solutions		
vii	Renewable energy selection		including NPC analysis
viii	Determine time taken to achieve carbon neutrality for village.	(vi) plus (vii) above and deduct from (v)	
5	Additional Energy Reduction Methods		
ix	Retrofit building with thermal ceramic coating.	Spray outer skin with various thicknesses of ceramic coating	Monitor thermal improvement in separate experiment.
6	Generic tool development (LEVI) and application to MMG		

Table 3.4: Outline of the order of the research

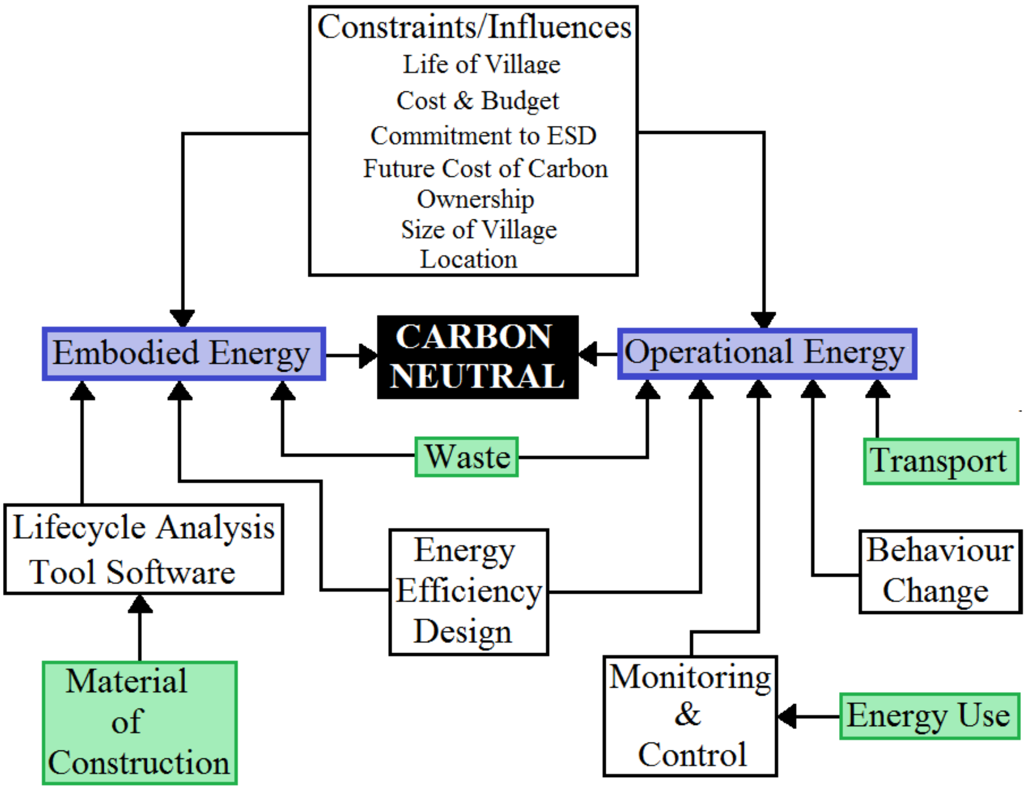


Figure 3.14: Conceptual model for calculating carbon neutrality in mine site villages (Goodfield *et al.*,b2011)

3.1.2 Calculating embodied energy

Life cycle analysis (LCA) has a prominent role in all areas where carbon emissions need to be quantified. Determining the physical and system boundaries of any calculation of carbon emissions is ‘fundamental as is the method adopted’ (Horne *et al*., 2008).

The software tool referred to in Chapter 2 eTool® makes use of the three internationally accepted methods used to calculate the embodied energy of buildings and infrastructure and is applied here to MMG. These methods are: carbon inventory analysis of scope 1 and 2 emissions, as defined by the Commonwealth Government (DCCEE, 2010); life cycle analysis (LCA), a method supported by the International Energy Association outlined in AS/NZS ISO standard *14040:2006* which states that the assessment is conducted for impacts throughout a product's life, in this case from ‘cradle to gate.’ In this instance the LCA includes the emissions from the materials and processes of construction and site installation but not the removal for reuse or disposal and remediation of the site; and finally, carbon profiling, a modification of LCA to include the emissions associated with land development itself according to the fuel consumed and its emissions factor when applied to a specific location (Hamilton *et al.*, 2007). The carbon account requires the system boundaries of where the responsibility for the emissions lays to be defined.

Once MMGs overall footprint is calculated, following the process detailed in National Carbon Offset Standard Guidelines (NCOS, 2013) the process of offsetting it can commence. This includes: reduction of the embodied energy of construction; implementation of operational energy efficiency measures, including behaviour change; introduction of renewable energy system offsets; and accredited offset purchases of carbon credits sold on the international market; all designed to achieve carbon neutrality within a defined period with each process measured by the mass of carbon they reduce the overall footprint by.

For the overall MMG carbon footprint calculation the energy efficiency measures and behavioural changes, in terms of carbon reduction, were estimated. These estimates were based on the results of previous research conducted by the author and by observation at MMG (Anda *et al*., 2007 & 2008).

The anticipated life of the village is an important factor in determining the annual proportion of the total embodied energy MMG village is responsible for. This will be determined at the outset by the mine owners according to their view of the viability of the resource and the longevity of the enterprise. Commodity markets are volatile and will affect the life of the operation and its need for supporting village accommodation and infrastructure.

It was decided that a life cycle approach was appropriate here to include within the boundaries of the LCA the manufacture and transport of the buildings to MMG and the construction of the village. As the longevity of the village is an unknown factor the buildings were treated as disposable at the end of their life – not the most sustainable solution but a practical one in the circumstances.

3.1.3 Calculating the emissions to operate MMG

There are six areas where the MMGs emissions were measured or estimated, as included in figure 1.2 and in Goodfield *et al.*, (2011). These six areas are:

(i) The **operational energy** – the energy consumed on site generated by gas and diesel fuelled generators at the mine site itself and connected to the village by an 8km spur line. The overall energy consumption was determined by MMG's electrical engineers based upon information provided by Engen Ltd, the contractors responsible for the mine's generators and fuel supply. An energy audit and installation of a comprehensive monitoring system enabled a breakdown of energy consumption within the village.

(ii) The **transport of personnel** by air from Perth (Fi-Fo).

(iii) The **delivery of food** and general supplies to and from MMG was estimated and the emissions from the fuel used calculated.

(iv) The emissions from the production of the **food** consumed in the village.

(v) The emissions from the energy required to desalinate and supply locally drawn bore water and to treat it in the WWTP was included in element (i) as part of the operational energy.

The fugitive emissions from the **WWTP and waste water disposal** were calculated in this section.

(vi) Emissions from **solid waste disposal** to the RMS landfill site were assessed.

An overview of the process for the calculation of the carbon emissions MMG is responsible for is shown in table 3.5 below:

Factors	Explanation
GHGs included in calculation	There are many gases with global warming potential. The GHGs are represented as CO $_{2\text{-e}}$ or CO$_{2\text{-equivalent.}}$
Accounting methods	(i) LCA by input- output method, process analysis or combination, as used by eTool. (ii) Using metrics from the National Greenhouse Accounts (NGA) Factors [based on GHG Protocol].
Accounting period	The time period over which the carbon emissions are accounted for.
Boundaries	The point at which the LCA ceases to be part of the carbon account. This includes scopes 1, 2 and 3 as defined in the NGER Act, 2007.
Carbon reduction & offsets	Renewable energy or purchased ACCUs. All offsets accredited according to legislation and international standards

Table 3.5: Factors in calculating carbon emissions

The areas of the village covered in the carbon accounting process are set out in table 6 below together with a brief description of the tool used to calculate the emissions:

Facility/Operation	Carbon source	Tool or method of calculation of carbon emissions
1. Accommodation & General Buildings,	Embodied energy of built form & service infrastructure.	eTool™ freeware accessible at **http://app.etool.net.au/** . All calculations certified by Henrique Mendonca, certified assessor employed by eTool.
plus transportation from Perth manufacturer to site...	Fuel used	Fuel consumption rate/tonne.km & National Greenhouse Account Factors (NGA, 2014)

2. Operational Energy	81% LNG and 19% Diesel power generation at mine	Data from RMS & monitoring. (MMG Energy – Appendix 2)
3. Transport of supplies	Delivery of supplies from Perth to MMG	Fuel consumption rate/tonne.km & National Greenhouse Account Factors (Gov. of SA, 2009).
4. Fly In – Fly Out transport	Air travel – 8 days on/ 4 off roster	Local Government emission calculation worksheets (Gov. of SA, 2009). (GHG Protocol 1^y source)
5. Water Supply & Waste Water Treatment	Desalination plant & WWTP energy use	National Greenhouse Account Factors (NGA, 2014).
6. Solid Waste	Mixed waste to landfill	National Greenhouse Account Factors (NGA, 2014).

Table 3.6: Facilities and operations covered in carbon account, process and applied tools

Further detail of nos. 1 -6 in table 3.6:

1. **Accommodation & general buildings**

The embodied energy of buildings and the infrastructure to service them consumes up to 40% of global energy consumption and produces 30% of the world’s carbon emissions (UNEP, 2009). It, therefore, can provide a significant proportion of the carbon footprint of MMG Village.

An online modelling tool for the calculation of a building’s embodied energy, known as eTool™, has been used to calculate this embodied energy The tool applies internationally recognised life cycle inventory database methodology and algorithms specific to Australia and complies with ISO 140040 to 14044:2006.

2. Transport of buildings

The buildings were constructed in a Perth southern suburb and transported on a single trailer for the 600km journey to Mt. Magnet- see figure 3.15 below. Average fuel consumption figures per tonne per km were provided by Australian Greenhouse Office as applied in peer reviewed Greenjourney paper (CERES, 2007). Fuel combustion emission factors for fuels used for transport energy purposes were provided by the National Greenhouse Account Factors National Greenhouse Account Factors (NGA, 2014).

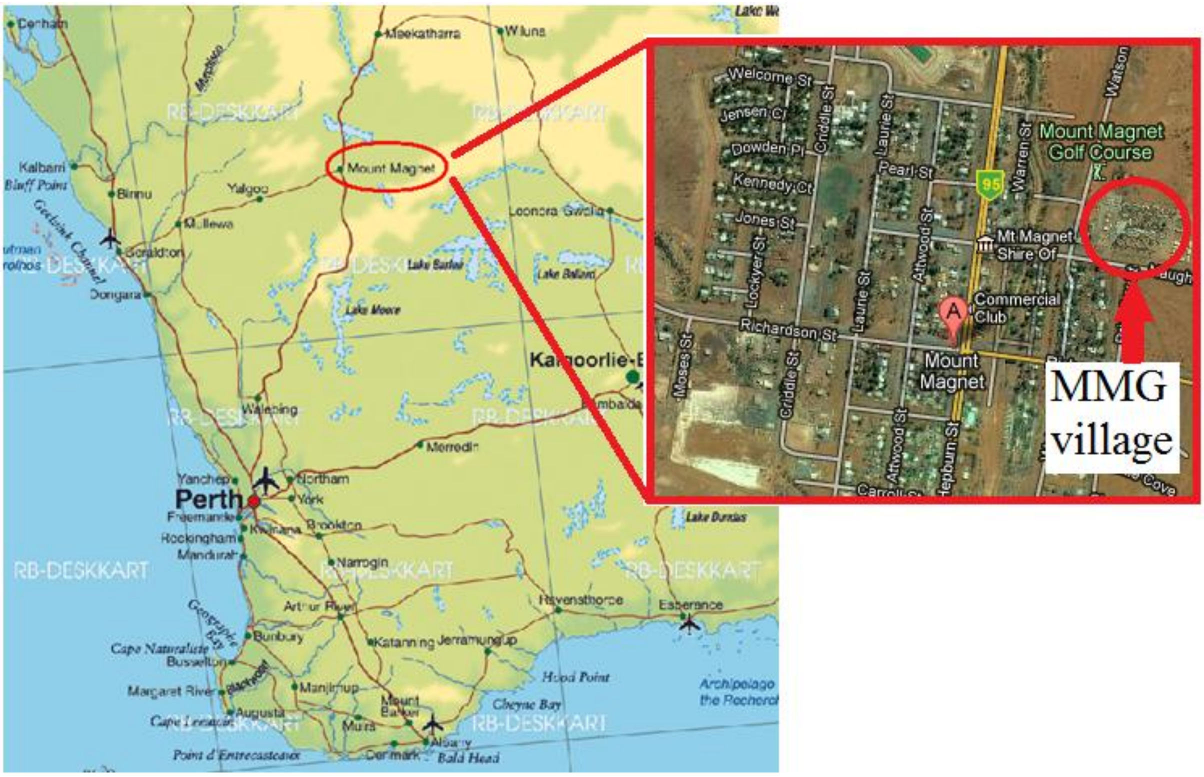


Figure 3.15: Mt Magnet location

3. Operational energy

Discussion with Engen Ltd, who lease the mine site power plant to RMS, confirmed that fuel for the energy production was in the ratio of 81:19 liquefied natural gas (LNG) to diesel. The NGA Factors (DCCEE, 2010:15) details the fuel combustion emission factors for liquid fuels and certain petroleum based products for stationary energy purposes. The annual volumes of gas and diesel consumed were for also provided.

4. Transport of supplies

Carbon emissions from road transport of supplies for food, groceries and other deliveries, are the same as in item 2. The calculation is based on truck delivery from Perth.

5. Fly In – Fly Out (Fi-Fo) transport

Scope 3 emissions cover the transport element of emissions, from mining workers' places of normal residence to MMG, but are much more difficult to calculate definitively due to the disparate geographical location of the domestic residences.[1] According to the GHG Protocol (2010: 27) the GHG Protocol is "an optional reporting category that allows for all other indirect emissions," which includes travel to and from work.

The calculation was done by determining the carbon emissions per km per person for medium haul flights (>500 km and <1600 km) are set out in the World Resources Institute CO_2 Inventory Report (2010:11), following the GHG Protocol. It was assumed that MMG staff all fly from Perth, although many access Perth Airport from considerable distances further away and some travel from areas closer to Mt Magnet.

6. Food consumed

The food consumed at MMG of locally grown and imported food has a carbon footprint which can be calculated according to the national averages provided by government publication in SMEC (2008: 21).

7. Water Supply & Waste Water Treatment

Bore water is supplied from a bore between MMG and the mine and is pumped to be stored at MMG. Energy is required to desalinate this groundwater, distribute it for camp use, return the waste to the waste water treatment plant, treat the waste, and finally pump out to

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[1] MMG residents were asked where they travelled from to establish this.

secondary treatment ponds outside the camp. Energy required for desalination and distribution at MMG is accounted for in the overall operational energy calculation (no. 3 above). The bore water for the village is extracted at the same point and time when the mine requires water. The proportion required by the village is < 0.001% of that required by the mine and the proportion of energy required to supply it is therefore is negligible.

The anaerobic treatment process in WWTP produces fugitive emissions of methane which are not captured and are released to the atmosphere. An aerobic treatment process follows and the waste water is pumped to settling ponds where fugitive methane emissions occur.

8. Solid waste

Detail of the amounts of solid mixed waste sent to RMS' private landfill was provided by MMG staff. The NGA Factors provides detail of greenhouse emissions from landfill (DCCEE, 2010 at 46).

3.2 MMG monitoring and data collection

The overall layout of the buildings at MMG can be seen in Appendix 2 and a schematic representation of the monitoring equipment setup for both power and water in in Appendix 3. Using its experience from previous village sites MMG's construction company determined significant areas of water and power use to meter and monitor. Pulse output sensors were attached to several water meters (see appendix 3) and to a data logger. Power supplies to two 4-bed and accommodation modules, the kitchen and mess, laundry, administration and gymnasium, were selected for monitoring. The major circuits that supply these buildings were then selected which for each circuit consisted of a current transformer to detect current, a digital sensor, and connection to a logger for data collection. Six data loggers in all covered both water and power across the village, each connected to a radio transmitter.

Data from the six transmitters was collected by a similar receiver which in turn was connected to the internet via a dedicated IP address enabling 24/7 access from any computer. Due to the volume of data and potential security issues a separate phone line for internet access was installed to which the modem was connected.

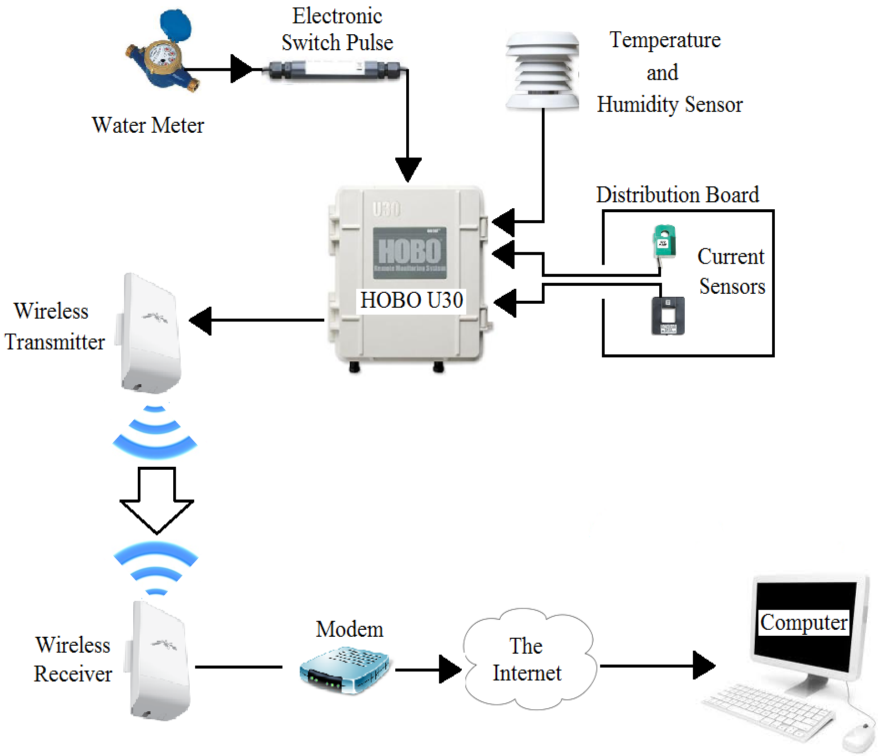

Figure 3.16: Deployment of the monitoring system

Agreements with both the mining company owners of the site and village construction company were formalised in order to facilitate permissible access in order to install metering and monitoring equipment, data collection and transmission devices, and access to staff during the currency of the research. The monitoring equipment was deployed as shown in figure 3.16 and with data routes shown in appendix 3. The first drawing shows the connections for water and wastewater monitoring, and the second for the monitoring of the power circuits.

The monitoring system operates as follows:

(i) For power monitoring, current transformers (sizes between 50 A and 600 A) sheathed a single live cable of the selected circuit to pick up the route mean square voltage. The current is then transduced by a digital sensor and the data sent to the HOBO™ data logger for storage. The stored data is then transmitted (wireless radio frequency) at hourly intervals to a receiver attached to a modem and sent to a ‘cloud-based’ storage set up by HOBO™ (see Appendix 4 for photographs and page 5 of the report to Matricon Ltd for the list of equipment in appendix 8).

Access to both the live and stored data is obtained online via a dedicated IP address from any computer anywhere at any time. For backup there was a ‘cloud’ connection for bulk storage of the large volume of data.

(ii) For water monitoring, a sensor is attached to the water meter with data transmission and storage is as in (i) above.

The monitoring system enabled the collection of a substantial amount of data for subsequent analysis. To fill gaps for circuits that were not able to be monitored a level 2 energy audit, according to AS 3598:2000, was undertaken. One aim of the analysis was to report to Matricon Ltd (the village construction contractors and electrical design and installation engineers) with a strategy for energy reduction in terms of technology and materials of construction choice, as well as appliance modification and selection. The report can be found in Appendix 5 together with the results of the monitoring of the major energy consuming areas - dongas, kitchen, administration (inc. communications), laundry, desalination and water treatment plant. Appendix 4 also includes the peak energy analysis for these areas.

3.3 Calculating the carbon footprint of MMG Village

Calculating the overall footprint of MMG Village is clearly a complex process and not an ‘exact science.’ Drawing the boundaries of what to include in the calculation in this research requires a certain level of subjective reasoning, but does follow the appropriate standards. Essentially, the footprint has been compiled by asking the question, “by going to work in a mine site village, how much extra carbon is the individual responsible for than by merely working from home?” Establishing a footprint gives a starting point from which to apply methods of reduction, which are also quantified, in order to reach a point of carbon neutrality if possible in a sustainable manner.

The first practical activity was to visit the site to observe the operation of the camp, set up the monitoring system described earlier, and to gather baseline data. The monitoring system setup has already been described. As mentioned in section 3.1 a level 2 energy audit was made to determine where the village’s energy was being consumed and to support the choice of areas selected for monitoring.

MMG village is connected to the mine’s power station via a 22 KV transmission line approximately 8 km long. The mine site power station consists of five 1.26 MW Deutz gas generators and three 0.7 MW Cummins and two 2.2 MW GM diesel generators (see figure 3.17).

Figure 3.17: Diesel power generators at MMG mine

Under normal operation the five Deutz gas generators provide the power along with one 0.7MW Cummins diesel generator to deal with load fluctuations. The remaining diesel generators are used in standby mode when large power loads are anticipated. The power system is not owned by RMS but leased to the company by Engen Ltd. RMS pay for the gas and diesel and Engen charge RMS on the basis of amount of fuel consumed.

According to Engen Ltd in 2011 the power supplied to MMG was only 2.46% of the total generation (figure 3.18). With the growth and full occupation of the village this has likely increased to between 3 and 3.5% according to Engen Ltd.

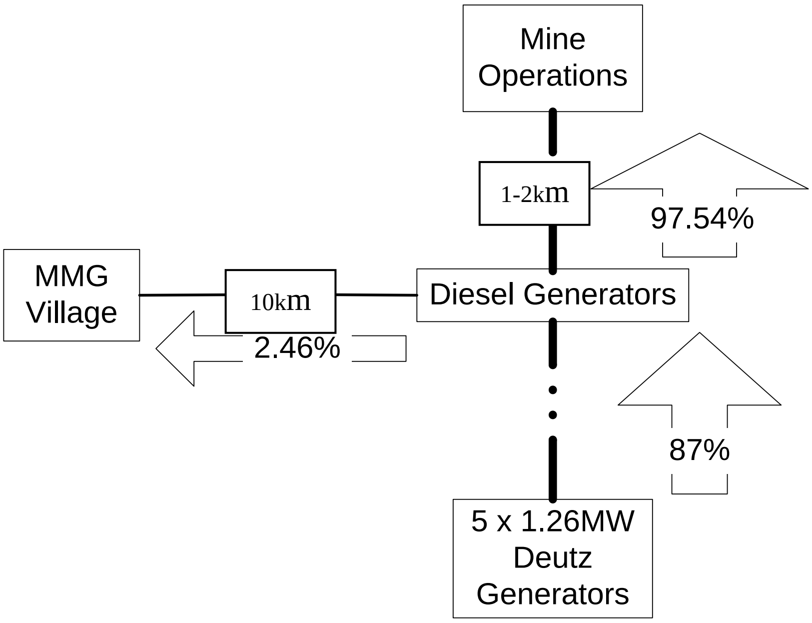

Figure 3.18: MMG power generation and distribution of supply[2]

According to electrical engineers, Matricon Ltd, the specification of the power system was as in figure 3.19 below and later used in the results section for calculations based on the data collected during monitoring.

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[2] 13% of the energy being provided by the Cummins diesel fuelled turbines and 87% by the Deutz gas turbines

Specification	Detail
Supply	3-phase
Voltage	240V
Frequency	50Hz
Load Power Factor (p.f.)	0.948 lagging
Max. permissible site volt drop	7%
Actual site volt drop	6.66%
Installation type	AS/NZ3000:2007 Commercial

Figure 3.19: MMG Village Power supply detail

(Matricon, 2011)

Details of the findings regarding load distribution, load profiles and energy consumption can be found in results section 4.2.

3.4 Carbon reduction methods

The carbon emission reduction process referred to in the conceptual model (figure 3.14) is comprised of five main areas of investigation:

1. Energy efficient construction and design.
2. Behaviour change to adopt new practices, more energy efficient infrastructure and sustainable systems.
3. Monitoring and control systems (smart systems) within a digitally integrated system.
4. Renewable energy systems.
5. Biomass, soil carbon or forestry offsets purchased from accredited providers.

3.4.1 Energy efficient construction and design

There are a multitude of ways to improve the sustainability of mine site villages, from the standpoint of energy efficiency through to improved liveability and social cohesion. It is beyond the scope of this thesis to cover them in any detail other than to refer to them as examples for further research and consideration. Areas to concentrate on would be: adherence to passive solar design principles in village layout and overall design; improved thermal performance and energy efficiency of the building envelope; smarter control of building access and occupation; and more efficient appliances. Several examples are referred to in chapter 2.

The thermal performance of the traditional accommodation module used in mine site village construction, the donga, and universal buildings of similar construction, has been a perennial problem. The donga is subject to rapid overheating in warm conditions and conversely to cooling quickly resulting in high air conditioning use. Translated into carbon emissions, if the use of active heating and cooling systems can be reduced, so will the reliance on fossil fuelled generation to provide the power. It is well known that air conditioning systems are frequently the left running during long periods of absence from the rooms. Any method to avoid or reduce the carbon emissions from this source, if financially viable, is a good objective to pursue.

3.4.1.1 Thermal performance improvement of mine site accommodation modules using a ceramic coating.

One solution, to improve the thermal performance and energy efficiency of the donga, is dealt with in detail here following testing of its energy efficiency improvement by the application of a thin coating of a ceramic material. An experiment was run to compare a coated donga with an untreated one under controlled conditions.

Two 6m x 4m lightweight transportable office dongas were supplied and installed at the Environmental Technology Centre, Murdoch University. One was sprayed with an average coating of 0.6mm thick Mascoat Industrial™ ceramic coating, followed up later by a further coating to a thickness of 1mm, leaving the other untreated.

The product is a composite ceramic & silica-based insulating coating that provides a reflective and insulating barrier. The coating substantially reduces heat transfer through a substrate; here it is the building envelope, primarily by reflection of the sun’s infra red rays. In addition the coating possesses insulation properties which added to its substantial reflective properties has proven to be an excellent method to reduce heat gain in lightweight transportable buildings.

A comprehensive monitoring system was set up to measure and compare the energy consumed by the air conditioner in each building, including room and wall surface temperatures as well as the outside temperature and humidity. Data was collected continuously for four months during late spring and early summer and analysed to determine the trend of any energy savings in running the air-conditioning in order to maintain a constant room temperatures of 22^{o}C and 24^{o}C throughout the two test periods.

In addition to the donga experiment two metal boxes were set up and one sprayed with 0.6mm of Mascoat Industrial™. The internal temperatures of the boxes were monitored in full sun for a period and the results compared. The two untreated dongas were set up as shown in figure 3.20 so that neither building was shaded by the other.

Figure 3.20: To show buildings' staggered positioning

One building was masked up and roof and all exterior walls sprayed with a priming coat (figure 3.21) using an airless spray application system, followed up further coating(s) to give a final overall average thickness of a minimum of 0.5mm. Later in the experiment the thickness was increased to a minimum of 1mm (figure 3.21a).

The energy consumption of the air condition systems in the two dongas directly reflects the thermal properties of the coated building when compared to one which is uncoated. In turn the energy consumed by the air conditioners can be directly translated into diesel fuel or gas consumption to generate the electrical energy for their operation. The reduction in consumption in these fuels can then be translated into carbon emission reduction in the form of carbon dioxide equivalents, $CO_{2\text{-e.}}$

Figure 3.21: Primer coating being applied.

Figure 3.21a: Coating thickness measurement

In order to compare the effect of the coating on the thermal properties of the coated donga with the uncoated building, the buildings were monitored under three separate conditions: with the air conditioning unit set at 22^{o}C; set at 24^{o}C; and with the air conditioning turned off. The windows and door were kept closed at all times.

A 20 Amp current transformer (figure 3.22) was attached to the live cable supplying the air conditioning unit which in turn was connected to a sensor and then to a data logger. Surface temperature sensors were fixed to the inside and outside of each donga north-facing wall and, together with an internal room sensor and outside weather station, all data was collected by the logger for analysis. The equipment used was the same as that deployed in MMG Village except the data logger was downloaded manually rather than transmitted by internet.

After a short time into the experiment the power consumption of the two air conditioners was remeasured and found to be sufficiently different to warrant replacement. Clearly, as the energy used by the two units in the two buildings was the central part of the research the air-conditioners were replaced by brand new units and the experiment repeated.

Figure 3.22 Current transformer

Figure 3.23 Metal boxes

In addition to the donga experiment two metal boxes 1200L x 1200W x 600H were positioned close to the dongas (figure 3.23). One was coated with an average coating not less than 0.5mm and monitoring equipment set up inside with the open end inverted to prevent airflow.

All results can be found in Chapter 4, section 4.3.1.1.1

3.4.2 Behaviour change

No commitment to discuss behaviour change programs and education could be given by either MMG operators (a contractor for RMS) or the village owners, RMS. As mentioned in earlier, RMS’ environment office was more concerned with environmental impact and compliance therewith, and other departments with occupational health and safety. Consequently an estimate had to be made of the likely effect such programs would have on carbon emission reduction. The assessment was based on two prior studies that the author contributed to, as referenced in earlier sections (Anda *et al*., 2007 & 2008).

3.4.3 Renewable Energy Selection

Before assessing the potential deployment of RE system(s), the background to MMG's current power system, the type and degree of penetration into the current power system, the current village energy demand and load profile and energy demand forecast must be analysed. The appropriate RE system(s) would then be selected according to the village latitude for PV and weather data for wind, and according to the financial viability of it/them for a variety of project lives from 5 to 20 years. To round off a sustainable solution to reducing MMG's carbon footprint a financial analysis is required, also projected forward to 2018 to take into account the predicted fall in the cost/watt of RE from wind and PV sources and the increase in diesel fuel and LNG.

(i) Energy demand – the energy demand at MMG needed to be determined prior to dealing with alternative means of managing it. Annual energy consumption details were provided by BEC Engineering Ltd to Matricon, MMG electrical engineers, for their assessment of demand based upon historical data. Monthly predicted loads were made available from which hourly load characteristics were produced. Following the extensive data collection individual circuit characteristics and load profiles were possible for comparison with the predicted loads.

(ii) Current power system – refer to section 3.3for detail.

(iii) Identification of technologies – the method follows the pattern shown in figure 3.24. This pathway was followed to determine which RE systems to consider as feasible to install at MMG Village.

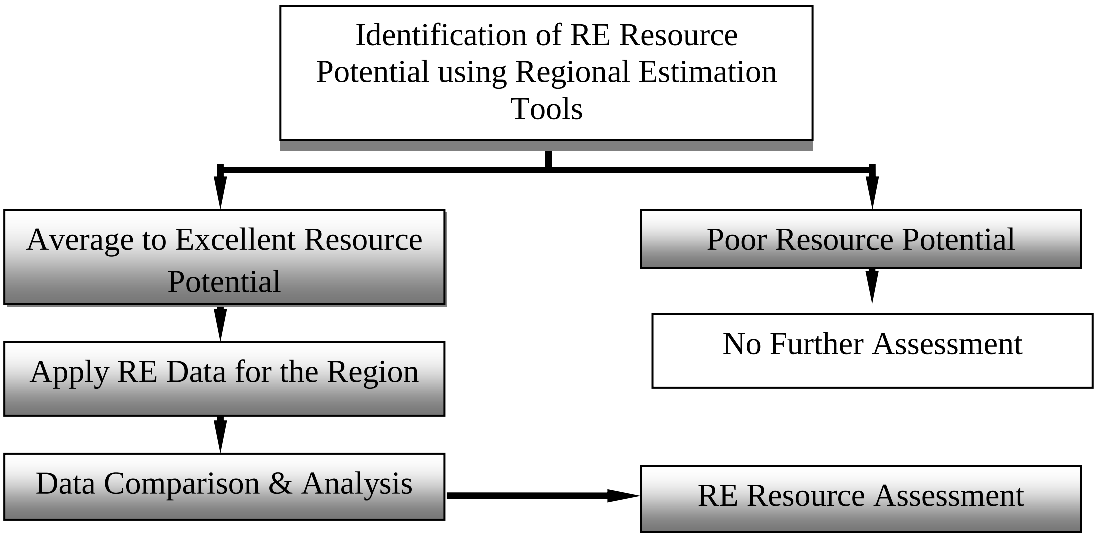

Figure 3.24 Resource assessment method (Ploumis, 2011)

A multi-criteria analysis (MCA) was selected by: identifying relevant stakeholders; weighting the criteria; and identifying the RE options and rating them.

Identifying relevant stakeholders – as in figure 3.25;

Identified Stakeholders
- Head office - MMG village employee - MMG village resident - Mt Magnet community

Figure 3.25: RE power system stakeholders

The basis for identifying the RE options was a quadruple bottom line approach, to include technical factors, as set out in figure 3.26.

Social	**Environmental**	**Economic**	**Technical**
- Education on use - Health and safety - Employment - Social acceptability - Social benefits	- Materials use - Energy use - Biodiversity - Emissions - Compliance - Land use - Aesthetic	- Capital cost - Operating cost	- Efficiency - Reliability - Maturity - Implementation duration

Figure 3.26 Criteria for installation of RE power system at MMG (Ploumis, 2011)

The RE selection was from PV, wind, solar thermal, biomass and concentrated PV. The results can be viewed in the next chapter.

(iv) Resource assessment – following the MCA determination of the most appropriate RE system or systems to install at MMG depends upon two main but linked scenarios: retrofit or new installation; and standalone or grid connected configuration.

The selection of RE at MMG was complex. The method for standalone systems was based upon the use of the internationally accepted modelling tool HOMER® (Hybrid Optimisation of Multiple Energy Resources) for use in designing hybrid RE microgrids, by simulation, optimisation and sensitivity analysis. The tool is designed for analysis for standalone systems only.

The alternative for the installation of RE systems to reduce MMG's diesel and LNG use is for the system(s) to remain connected to the MMG grid. For this purpose HOMER had to be modified and alternative software, developed described as REMAX.

(v) A financial analysis was then applied to the results of the RE modelling.

The process of evaluation of what is the most sustainable solution to reduce MMG's fossil fuelled energy use is a complex process. Section 4.4 sets this out and highlights the results of the process.

Chapter 4 – Results

4. RESULTS

The overall aim of the thesis is to develop a carbon neutral model for the case study mine site village (MMG) that can be applied to similar village development as well as on a broader scale to the urban development generally. A generic model, LEVI (Low Energy Village Infrastructure), was accordingly developed and can be seen in Appendix 10 along with its specific application to MMG. The research questions are answered individually in this chapter.

4.1 Research Q1

What are the constituents of the MMG carbon footprint and how are they calculated?

The carbon footprint of MMG is comprised of the sum of several parts: the embodied energy of the built form and service infrastructure; from the production of food consumed on site; and the energy used to operate the village as a whole. The constituents of the footprint have been calculated as the carbon emissions from:

- The embodied energy of the accommodation and general buildings.
- The transport of the buildings from manufacturer to site.
- The stationery energy to operate the village.
- The transport of supplies to the village.
- The production of food consumed in the village.
- Fly-in/fly-out transport to the village.
- Waste water treatment.
- Landfill waste.

4.1.1 Accommodation & General Buildings, Embodied Energy

The embodied energy over the four life spans has been calculated using the software known as eTool™, details of which have been discussed in the chapter 2. The results for the various projected life spans can be seen in table 4.7 below and has been certified as correct by the eTool™ software developers (certificates can be found Appendix 6). It has produced some interesting results in that over a 5 year lifespan the embodied energy of the village amounts to approximately 33% of the total carbon footprint. However, if the lifespan is extended to 20 years then the embodied energy only forms 11% of the village carbon footprint.

The proportions of MMG's carbon emissions for 5 and 20 year life spans are shown in figures 4.27 and 4.28 are substantially different and vary according to the projected life span of the village. These life spans have been selected to demonstrate the contrasting embodied energy apportionment in each. The longer the projected life of the buildings and infrastructure, including the transport emissions to deliver the buildings to MMG from the manufacturers, the greater the amortisation of the overall energy, which for a 5 year life span is 1066 tonnes $CO_{2\text{-}e}$ and for 20 years is 267 (as per table 4.7). Recurrent energy expenditure, has been accounted for in the eTool embodied energy calculations to cover replacement and maintenance, such as painting and appliance replacement.

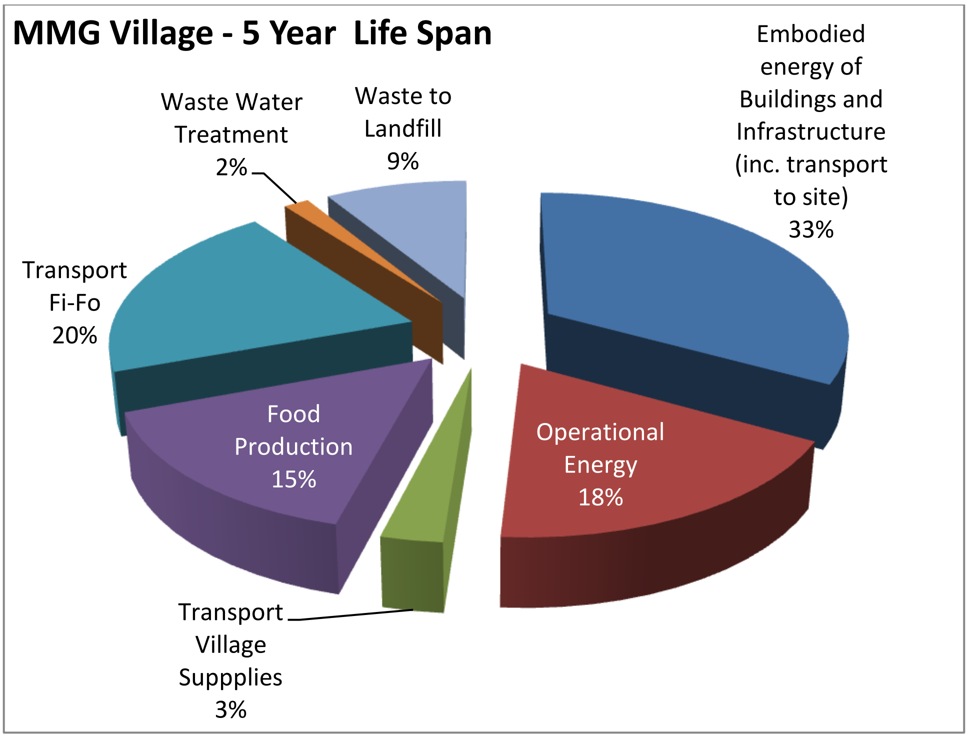

Figure 4.27: Proportion of carbon emissions for full LCA of MMG with life span of 5 years.

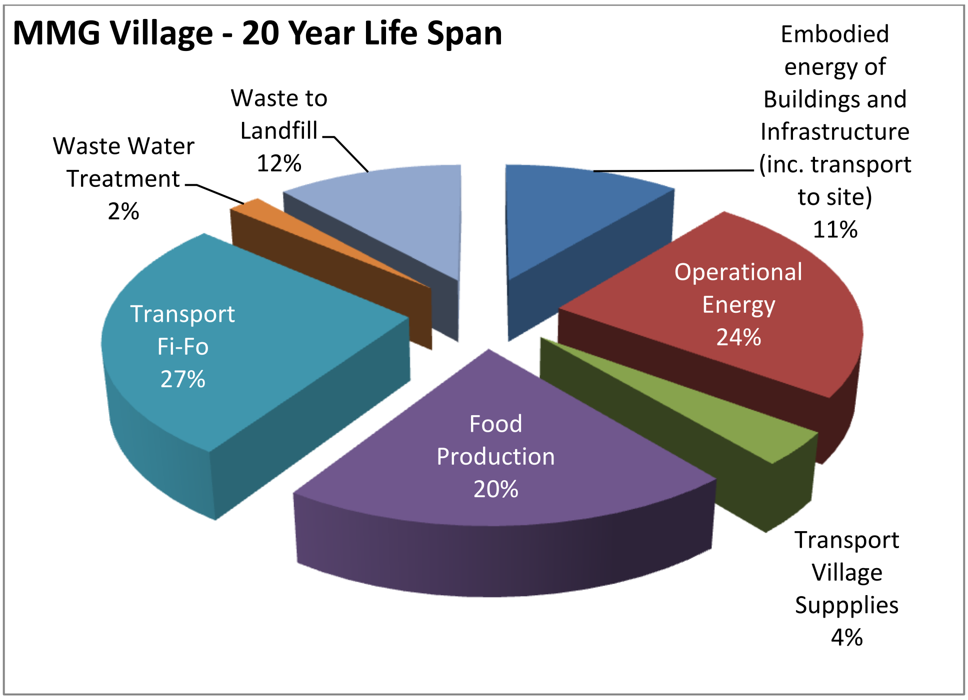

Figure 4.28: Proportion of carbon emissions for LCA of MMG with life span of 20 years

Embodied energy of accommodation & other buildings and building delivery transport (tonnes CO $_{2-e}$)	**Village lifespan (Years)**	**Annual embodied energy (tonnes CO $_{2-e}$)**
5330	5	1066*
5330	10	533*
5330	15	356*
5330	20	267*

Table 4.7: Embodied energy of MMG village over 5, 10, 15 & 20 year life spans

* Rounded figures

4.1.2 Transport of buildings to MMG

The buildings are all manufactured in a southern suburb of Perth and transported by road to Mt Magnet for final assembly and 2nd fix of site services. The calculation for fuel used, and consequential carbon emissions, is made by moving buildings by road from the factory 10 km south of Perth to MMG (see map in figure 3.15).

The calculation of the diesel fuel consumed by truck to deliver the buildings, and return empty to Perth, is set out in table 4.8.

Journey	Load	FCR	Distance km	Litres Diesel
Henderson to Mt Magnet Single axle trailer - loaded	30 tonne - loaded	0.546 L/km*	602	= 0.546 x 602 = ***328.7***
Mt Magnet to Henderson Single axle trailer – unloaded	25 tonne - unloaded	0.546 L/km*	602	= 0.546 x 602 = ***328.7***
			Total	**= 657.4 L**
FCR = Fuel Consumption Rate				

Table 4.8: Fuel and carbon emission calculations for road transport by heavy vehicle[3]

The logistics are such that a 25 tonne truck would transport a 4-bed accommodation unit from the factory in Henderson, W.A., on a single trailer to MMG without a wide-load escort. The carbon content of the diesel fuel used to complete the delivery of all buildings to MMG village can be seen in the Table 4.9 below and amounts to a total 81,592 litres to deliver the whole village to site in Mt. Magnet 602 km north of the manufacturing facility. This volume of diesel amounts to 218 tonnes of emissions equivalent (NGA, 2010: 17).

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[3] * Note the overall tare of the single and unloaded fuel consumption remains the same in the above calculation. Rolling losses such as drag due to wind resistance are also not taken into account and an average L/km figure is, therefore, taken (AGO, 2006 in CERES, 2007: 12)

Trip type	Fuel/trip (Litres)	No. trips	Total Diesel (Litres)
Henderson to Mt Magnet Single trailer loaded	329 (see table 11)	124	40,796
Mt Magnet to Henderson - Single trailer unloaded	329	124	40,796
		TOTAL Diesel	81,592 L
Carbon emissions = 2.67 kg $CO_{2\text{-}e}$/ Litre Diesel oil			(NGA, 2010: 17)
Emissions equivalent of diesel		**= 217.9 tonnes $CO_{2\text{-}e}$**	

Table 4.9: Total diesel consumed for delivery of all buildings from manufacturer to MMG

4.1.3 Operational Energy

The source of the power used by MMG is Mt Magnet Gold power generation system at the site of the mine site some 8 km away (figures 3.17).

Most mining villages in Australia receive their power from a gas and diesel generation plant situated at the mine. Standalone systems are rare and are the exception rather than the rule (Swan Energy, 2013). MMG is connected to the mine’s power station via a 22kVA transmission line. The power station consists of five 1.26MW Deutz LNG fuelled turbines and three 0.7MW Cummins and two 2.2MW GM diesel generators (see figure 3.17 above). This power system is not owned by the mine owners RMS but leased from Engen Ltd. Charges are levied by a fixed monthly and variable fee , the latter dependent on the amount of diesel and gas consumed and energy produced by the power system.

Energy use for the complete mining operation is distributed as in figure 4.29 and shows the small proportion used by the village itself at 2.46% of total generation. MMG site electricians have confirmed that the village power load has no effect on the overall generation as generation is always a percentage above requirement, any excess generation being dumped to earth.

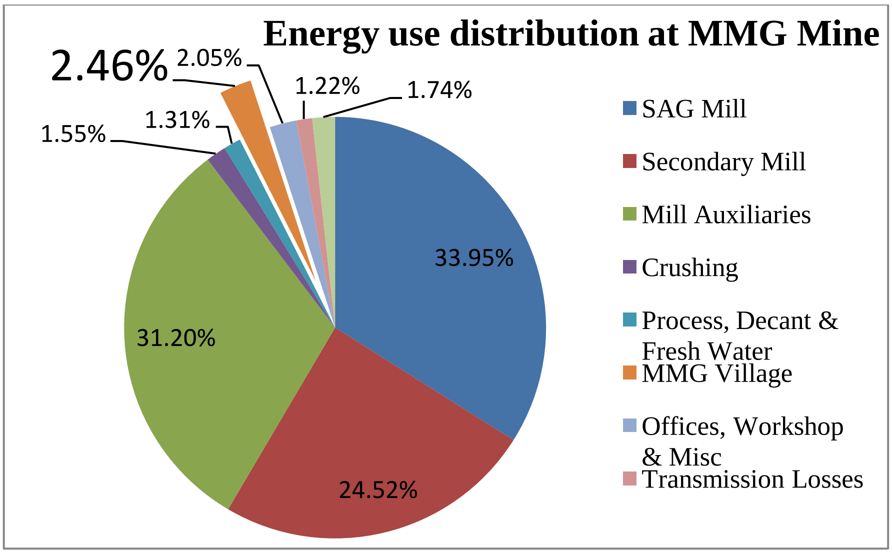

Figure 4.29: Distribution of energy use at Mt Magnet mine (BEC Engineering, 2011)

1.09GWh was the measure of MMG energy consumption for a period of 12 months at full occupation verified by Matricon Ltd and confirmed by the monitoring carried out during this research.

Energy consumed by MMG village	1085 MWh per annum				
		LNG			
		Turbine efficiency 37%	**Consumption @ 10.75 kWh/m^3**	**$\text{CO}_{2\text{-e}}$ content @ 1.99 x 10^{-3}**	**Tonnes CO $_{2\text{-e}}$ per annum**
81% **LNG**	878.8 MWh	2,375 MWh generated	220,930 m^3	**(tonnes/m^3)**	439.6
19% **Diesel**	206.2 MWh	**Diesel**			143.8
		Turbine generation @ 0.26 L/kWh		**$\text{CO}_{2\text{-e}}$ content at 2.683 x 10^{-3}** **(tonnes/L)**	
		53,612 Litres			
				TOTAL	**583.4**

Table 4.10: Carbon emission content of energy generated at MMG by LNG and Diesel fuels

The carbon intensity of this energy production was split between diesel and LNG fuels in the ratio of 19:81 according to information supplied by EnGen Ltd who lease the generators to RMS. The carbon content of this fuel use is 583.4 tonnes $CO_{2\text{-}e}$ p.a. as set out in table 4.10.

4.1.4 Transport of MMG supplies

The carbon emissions from the diesel fuel consumed by transporting food and grocery supplies to MMG once per week by truck from Perth are calculated in table 4.11 at 91 tonnes $CO_{2\text{-}e}$ per annum.

Mode	**Total Tare Delivery & Return**	**Distance (km)**	**FCR**	**Litres Diesel/weekly delivery**	**Litres Diesel/annum**
Articulated truck	30 tonnes	1204 (round trip)	0.546 L/km*	= 0.546 x 1204 = 657.38	= 657.38 x 52 = 34,184
				Total delivery diesel/annum	**34,100L**
Carbon emissions = 2.67 kg $CO_{2\text{-}e}$/ Litre Diesel oil (NGA, 2010: 17)					
				= 91 tonnes $CO_{2\text{-}e}$	

Table 4.11 Calculation of carbon emissions from diesel fuel to deliver food and groceries to MMG.

(* Note: Ref: CERES, 2007: 12)

4.1.5 Food Production

The production, packaging, storage and distribution of food, before it arrives on the plate, combine to be the most carbon intensive services that society is responsible for (DPI, 2008). It is appropriate to include an estimate using the following calculation:

Ave. annual consumption Aus. grown food (t./person*)	**Ave. annual consumption of imported food /person* (t./person*)**	**Emissions /tonne of Australian food ($t.CO_{2-e}$)**	**Emissions /tonne of imported food ($t.CO_{2-e}$)**	**Emissions /person /annum of Australian food ($t.CO_{2-e}$)**	**Emissions /person /annum of imported food ($t.CO_{2-e}$)**	**Total emission /person /annum of all food ($t.CO_{2-e}$)**
0.493	0.053	5.06	10.65	2.495	0.564	3.06
Total annual emissions from imported and Australian food consumed at MMG village by 162 persons						**495.7**

Table 4.12: Calculation of annual carbon emissions per person from both imported & Australian grown food.

(DPI, 2008: 21)

* Note: assumes 2.6 persons per household (ABS: 2007)

4.1.6 Fly-in Fly Out (Fi-Fo) emissions

Emissions for travelling by air from Perth to Mt Magnet are calculated in table 4.14 according to the World Resource Institute (WRI, 2003) scale of emissions (table 4.13).

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Air Travel		**kg CO_{2-e} per passenger km**
Short haul	< 500 km	0.15
Medium haul	500 to 1600 km	0.12
Long haul	> 1600 km	0.11

Table 4.13: Carbon emissions for air travel

(WRI, 2003)

Flight type	**Distance (1-way)**	**Tonnes CO_{2-e}/ km/person**	**Tonnes CO_{2-e}/ person/ flight**	**Flights/ person/ annum ***	**Tonnes CO_{2-e}/ km /person/ annum**	**Tonnes CO_{2-e}/ km / annum (160 persons)**
Medium haul	600	0.00012	= 0.00012 x 600 = 0.072	56	**4.03**	**644.8**

Table 4.14: Carbon emissions from air travel to and from MMG village

[Formula: Distance travelled (km)* x *emissions factor = t.CO2-e]

* Note: Roster is 8 days on 5 off, therefore 28 trips out and 28 return Perth per annum
= 56 flights/annum

4.1.7 Waste Water Treatment & Desalination

The energy required for desalination and waste water treatment was not recorded independently but is accounted for within the overall operational energy of the 1.09GWh referred to in section 4.1.3 above.

4.1.8 Energy to supply ground water for desalination

Figure 4.30 below shows the diesel powered plant which operates the ground water bore pump for both mining operations and MMG. The supply to MMG (V) spurs off the main supply to the mine (M) as in figure 4.31. No records were kept of the quantity of diesel used for extracting the bore water and none for the proportional split between the two supplies. There could not be, therefore, an attribution of the fuel used to supply MMG with water and consequently no carbon emissions included in the overall calculation. An estimate by RMS puts the proportion of diesel used here at 0.001 percent of the total.

Figure 4.30: Bore pump

Figure 4.31: Bore water supplies to mine (M) and village (V)

4.1.9 Waste water treatment

The waste water primary treatment, aeration and holding tanks can be seen in figures 32 and 33 below with the evaporation lagoons in figure 4.34. The calculation of emissions from the full process of waste water treatment at MMG has been made on a worst case scenario basis as far as the GWP of emissions from the processes are concerned.

The annual volume of waste water treated was disclosed by RMS and the calculation of carbon emissions of anaerobic treatment follows in table 4.15 below under guidance from the National Greenhouse Account Factors, 2010, which states:

> *The treatment process is characterised as a deep anaerobic lagoon. Based on internal records, the fraction of BOD that is removed and treated as sludge in an anaerobic digester is 0.54. Their CO2-e greenhouse gas emissions are calculated as follows.*
>
> (NGA Factors, 2010)

Note: There is no methane recovery from the anaerobic digestion setup at MMG and it is vented to the atmosphere.

Biological Oxygen Demand (BOD)

BODw (tonnes) = Population x DCw / 1000

Figure 4.32: Waste water primary receiver tank for anaerobic treatment

Figure 4.33: Waste water aeration and settling tanks

Figure 4.34: Evaporation lagoons

Once secondary treatment is completed in the WWTP the water is stored and periodically pumped out to settling lagoons (figure 4.34).

Variable	Default values
P	The population served and measured in 1000 persons and sourced from waste treatment records
DCw	The quantity in kilograms of Biochemical Oxygen Demand (BOD) per capita per year of wastewater. In the event that no waste analysis data is available, a default value of 22.5 kg per person per year can be use
BODw	Biochemical Oxygen Demand (BOD) in kilograms of BOD per year which is the product of DCw and population
Fsl	Default fraction of BOD removed as sludge. Should be readily available from internal records of wastewater treatment plants (default value of 0.29)
EFw	Default methane emission factor for wastewater with value of 0.65 kg CH_4/kg BOD
EFsl	Default methane emission factor for sludge with value of 0.65 kg CH_4/kg BOD (sludge)
Fan	Fraction of BOD anaerobically treated. This value varies according to wastewater treatment type. IPCC defaults are: Managed aerobic treatment – 0 Unmanaged aerobic treatment – 0.3 Anaerobic digester/reactor – 0.8 Shallow anaerobic lagoon (<2 metres) – 0.2 Deep anaerobic lagoon (>2 metres)– 0.8
CH4 - GWP	21 – the Global Warming Potential of CH4 used to convert the CH4 emitted from wastewater to $CO_{2\text{-}e}$
R	Recovered methane from wastewater in an inventory year, measured/expressed in tonnes

Table 4.15: Municipal waste variables and default values (NGA, 2010: 71)

Therefore, BOD = 162 x 22.5/1000 = 3.65 tonnes/ annum
= BOD x 1 x Fan x EFw x 21

Emissions from wastewater treatment calculation:

= BOD x 1 x Fan x EFw x 21

Fan EFw Default methane emission factor for wastewater with value of 0.65 kg CH4/kg BOD	Fraction of BOD anaerobically treated. This value varies according to wastewater treatment type. IPCC defaults are: Managed aerobic treatment – 0 Unmanaged aerobic treatment – 0.3 Anaerobic digester/reactor – 0.8 Shallow anaerobic lagoon (<2 metres) – 0.2 Deep anaerobic lagoon (>2 metres)– 0.8

Table 4.16: Emissions from anaerobic digestion of waste water

Therefore, BOD x 1 x Fan x EFw x 21
= 3.65 x 1 x 0.8 x 0.65 x 21
= 39.86 tonnes $CO_{2\text{-e}}$

Emissions from sludge calculation:

GHG emissions (tonnes CO2-e) = BOD x Fsl x EFsl x 21
= 450 x 0.54 x 0.8 0.65 x 21
= 3.65 x 0.29 x 0.65 x 21
= 13.76 tonnes $CO_{2\text{-e}}$

Therefore total emissions for treating MMG waste water, with no methane recovery,

= 50.6 tonnes $CO_{2\text{-e}}$ per annum, being the sum of waste water treatment and from sludge.

4.1.10 Mixed waste to landfill

The volume of waste disposed of in MMG Gold mine’s own landfill site (see figures 4.35 and 4.36) was observed and recorded during site visits. The fugitive methane emissions from the landfill are calculated below converted its GWP equivalent of carbon dioxide:

Figure 4.35 Progressive remediation of RMS landfill

Figure 4.36: Cut & fill at RMS' landfill site

The waste produced at MMG is classified as mixed and equivalent to commercial and industrial waste under the National Greenhouse Accounts (NGA) Factors, 2014 (table 4.17). The volume was estimated at 4.5m^3 of mixed waste per week containing a large proportion of putrescibles, and buried in RMS's landfill site. Due to its composite makeup the period of decay of the waste, and therefore methane producing lifetime is variable. The GWP of the annual volume of waste deposited has been equalised as an annual figure for the four life spans.

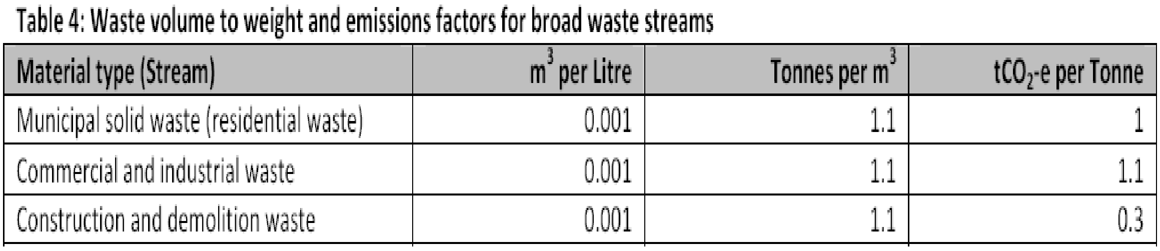

Table 4: Waste volume to weight and emissions factors for broad waste streams

Material type (Stream)	m^3 per Litre	Tonnes per m^3	tCO$_2$-e per Tonne
Municipal solid waste (residential waste)	0.001	1.1	1
Commercial and industrial waste	0.001	1.1	1.1
Construction and demolition waste	0.001	1.1	0.3

Table 4.17: Carbon emission conversion of mixed waste by volume

<u>Total mixed waste to landfill/ annum</u>

4.5 m^3 waste = 4.5 x 1.1 tonnes

= emissions of 4.95 x 1.1 tonnes/ CO $_{2\text{-e}}$ /week

= **<u>283 tonnes CO $_{2\text{-e}}$ /annum</u>**

4.2 Research Q2.

What is the carbon footprint of MMG, a typical mine site village?

Now that the all the constituents of the carbon account have been calculated a full account can be drawn. The emissions from the various components of the footprint for village life spans of 5, 10, 15 and 20 years are set out in table 4.18 below.

Item (i) in table 4.18 shows that the annual embodied energy of the built form with a projected lifespan of 5 years has been calculated to be 1066 tonnes CO_{2-e}, including the transport of those buildings from point of manufacture to site. It has been assumed that the buildings will not be recycled and reused elsewhere as is frequently the case with villages of short lifespan. The embodied energy of manufacture and installation is a one-off total and the longer the village is in operation the smaller each annual proportion becomes over time. The lifespan is, therefore, a significant factor in the total carbon footprint as the embodied energy is amortized over the longer periods.

Carbon emissions at MMG village per annum over a 5 year life span			**10 year life span**		**15 year life span**		**20 year life span**	
Facility/ Operation	**Emissions p.a. (t. $CO_{2\text{-}e}$)**	**Proportion of Total %**	**Emissions p.a. (t. $CO_{2\text{-}e}$)**	**Proportion of Total %**	**Emissions p.a. (t. $CO_{2\text{-}e}$)**	**Proportion of Total %**	**Emissions p.a. (t. $CO_{2\text{-}e}$)**	**Proportion of Total %**
(i) Accommodation & infrastructure, inc transport of buildings from Perth	1066	33	533	20	356	14	267	11
(ii) Operational Energy	583	18	583	22	583	23	583	24
(iii) Transport of supplies to MMG	91	3	91	3	91	4	91	4
(iv) Food production	496	15	496	18	496	20	496	20
(v) FI-FO	653	20	653	24	653	26	653	27
(vi) Waste Water treatment *	51	2	51	2	51	2	51	2
(vii) Solid Waste	283	9	283	11	283	11	283	12
TOTAL	**3223**	**100%**	**2690**	**100%**	**2513**	**100%**	**2424**	**100%**

Table 4.18: Carbon account summary of MMG with village life spans of 5, 10, 15 & 20 years

Note*: The energy required to desalinate and distribute fresh water is accounted for in item (ii).

The annual carbon footprint totals from table 4.18 can be apportioned to each of MMG's residents and represented in figure 4.37 for the four projected life spans.

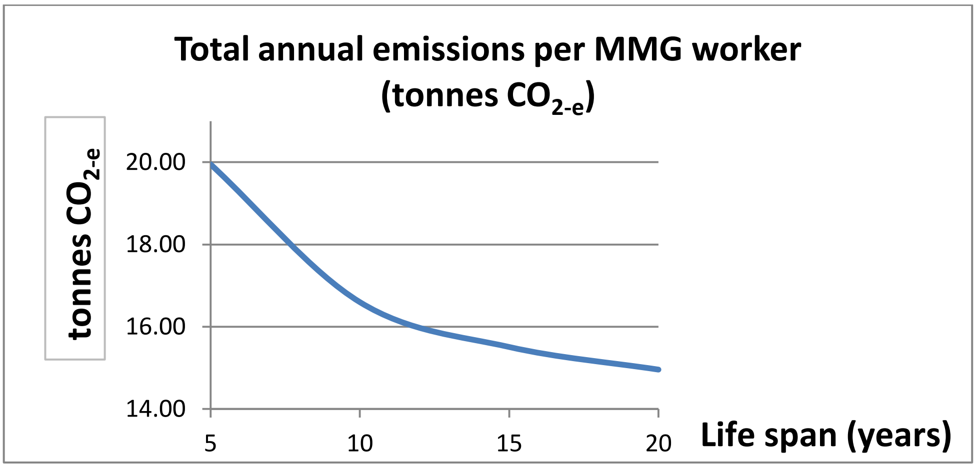

Figure 4.37: MMG individual annual emissions compared over various life spans of MMG

4.3 Research Q3.

What is the extent of carbon reduction when energy efficiency, behaviour change measures and renewable energy are applied and how much do they contribute to reducing MMG's carbon footprint en route to carbon neutrality?

The carbon footprint of MMG has now been established. In order to claim that the village can be described as 'carbon neutral' the total of the carbon emissions the village is responsible for must be reduced and the remainder offset so that the full footprint is accounted for within the sum of the reductions and offsets. There are several ways in which this can be achieved:

- Energy efficiency reduction (EE) by the use of new design, new technology and materials, and improved implementation procedure.
- Behaviour change reduction (BC) by modifying human behaviour to be more aware and conscious of the effects of certain activities.
- Reduction by substituting fossil fuel energy generation by renewable energy (RE).

- Purchasing accredited carbon offsets, such as accredited plantation forestry.

4.3.1 Energy efficiency and behaviour change reduction

Numerous examples of energy efficiency and behaviour change measures have been evaluated and employed in the built environment over time – refer to section 3.4.1 for examples. When it comes to sustainable development effective management of all elements that have an environmental impact requires assessment prior to and following implementation. As said previously, "in order to manage a process effectively it needs to be conscientiously monitored."

This thesis certainly relies on the inclusion of both energy efficiency and behaviour change measures in principle but it is beyond its scope to evaluate them for accurate determination. Consequently estimates have been made based on case studies. At outset of the research attempts were made to engage building manufacturers in the implementation of accommodation module (donga) design modifications but this was without success bar one exception. During the currency of the research a controlled study was set up to determine the thermal efficiency of a ceramic coating applied to the outside of a typical donga (refer to section 4.3.1.1.1).

First of all a general estimate of EE measures and BC possibilities, together with their carbon emission reduction capacity, were taken from previous studies (FMG, 2008. & RTIO, 2009). Table 4.19, was compiled resulting in EE and BC reductions of 281 tonnes $CO_{2\text{-}e}$/ annum. As percentage of the annual emissions for a 5 year village life span represents approximately an 8.7% reduction and for a 20 year village lifespan approximately 11.6%, as shown in table 4.20 below.

Reduction Method	**Detail**	**Carbon Reduction/annum**
1. Energy efficiency:		
i. Modified building construction design.	Passive solar village design, improved insulation, shade structures, additional solar water heating.	12.5% operational energy (estimate)* = **-73 tonnes CO_{2-e}**
ii. Smart control	Integrated BMS.	10% (estimate)* = **-58 tonnes CO_{2-e}**
iii. Laundry modification	Energy efficient appliances	= **- 2 tonnes CO_{2-e}**
iv. Roster change (→flight number reduction)	From 8 days On 5 Off to 10 ON 5 OF	56 flights 48 = **-93 tonnes CO_{2-e}**
iv. Grey water reuse of residential waste water	Reduces ½ vol. water to treat in WWTP	= **-25 tonnes CO_{2-e}**
2. Behaviour Change:		
i. Water use - desalination ii. Waste water - treatment	Efficiencies	- 10% (estimate) * = **-5 tonnes CO_{2-e}**
iii. General awareness	Overall awareness to reduce operational energy.	- 5% (estimate)* = **-25 tonnes CO_{2-e}**
	TOTAL	= **-281 tonnes CO_{2-e}** (Complete village)

Table 4.19: Energy efficiency and behaviour change examples with carbon emission estimated reduction (*Anda *et al.*, 2007 & 2008)

Lifespan of Village	**Emissions per annum over lifespan of village** (tonnes CO_{2-e})	**Estimated emission reduction per annum from EE and BC** (tonnes CO_{2-e})	**Overall reduction % p.a.**	**Remaining balance of carbon to reduce or offset/annum** (tonnes CO_{2-e})
20 years	2424	281	11.6	2143
15 years	2513	281	11.2	2232
10 years	2690	281	10.4	2409
5 years	3223	281	8.7	2942

Table 4.20: Deduction of energy efficiency and behaviour change measures from gross carbon emissions

4.3.1.1 Energy efficiency applications

A single modification to the built form of the standard donga is specifically considered here: the application of a thermal ceramic coating to the exterior walls of the accommodation modules.

4.3.1.1.1 Application of a thermal ceramic coating to the exterior walls.

The following is an extract from the results section of the final report of the Mascoat™ thermal ceramic coating experiment referred to in section 3.4.1.1 of the methodology chapter (see Appendix 7 for full report).

Data was collected and analysed to observe weekly trends in the energy consumed by the air conditioning system over the average coolest and average hottest week, and hottest single day and coolest temperatures during the monitoring period. The trends can be observed in figures 4.38 to 4.41.

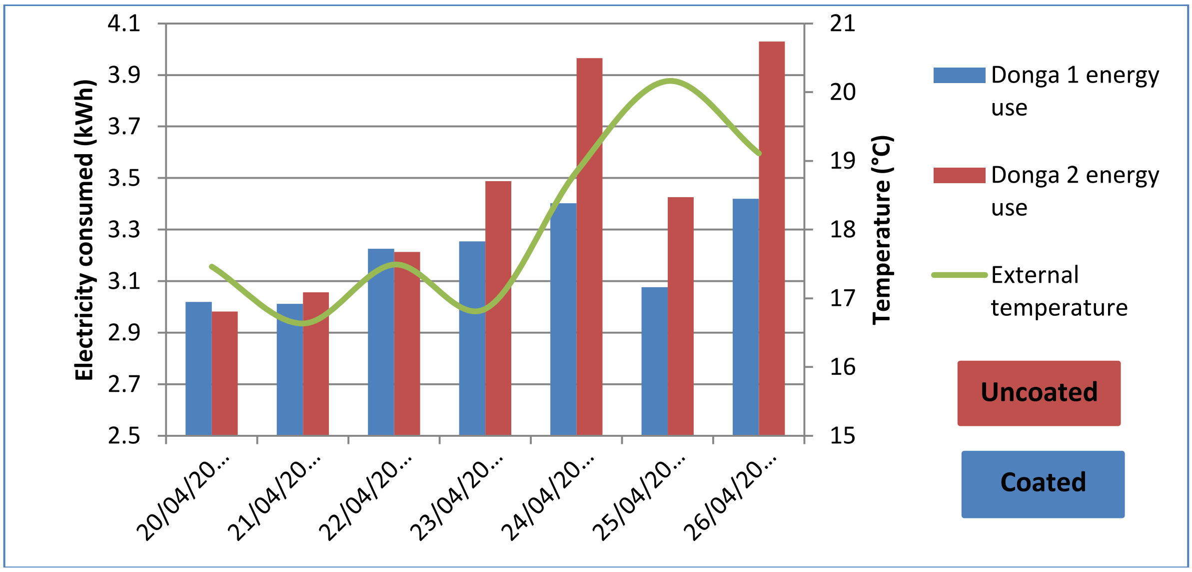

Figure 4.38: Air conditioning energy consumed over coolest recorded week

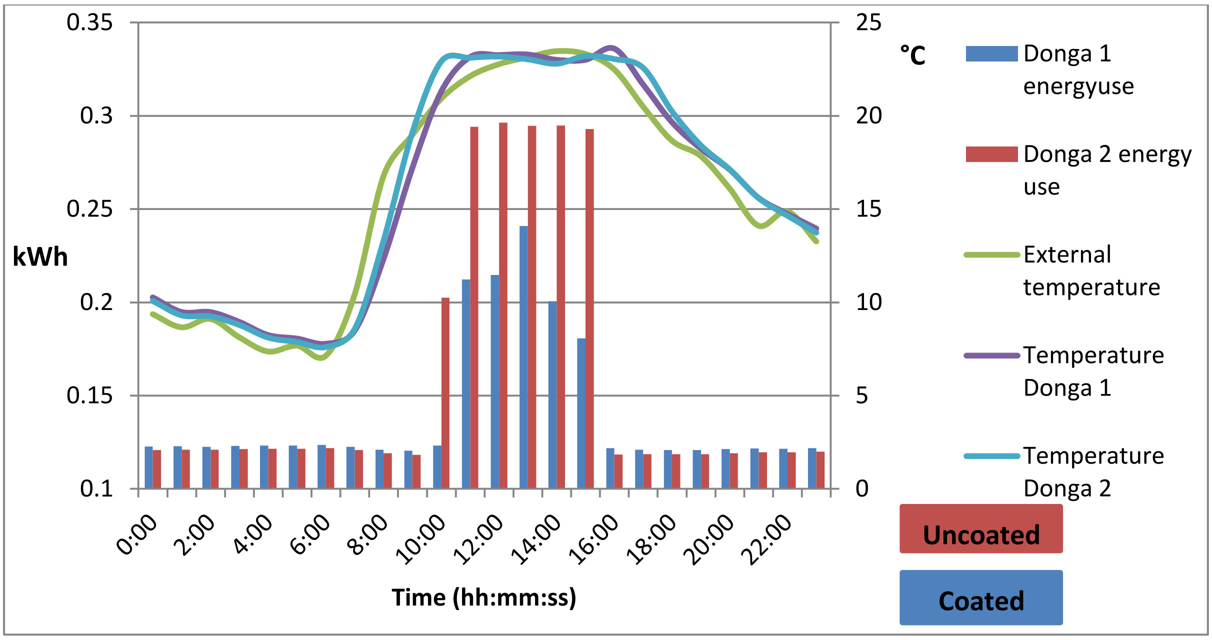

Figure 4.39 Air conditioning energy consumed over coolest recorded day

Note*: The baseline consumption of approximately 0.14kWh represents the energy consumed by the equipment.

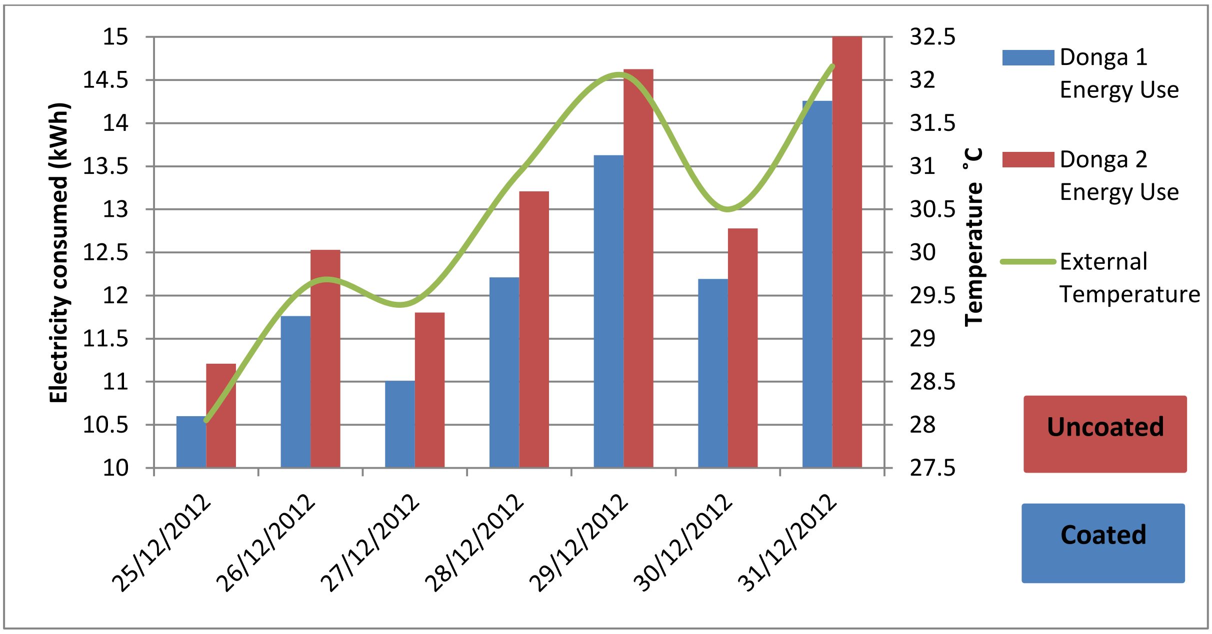

Figure 4.40: Air conditioning energy consumed over hottest recorded week

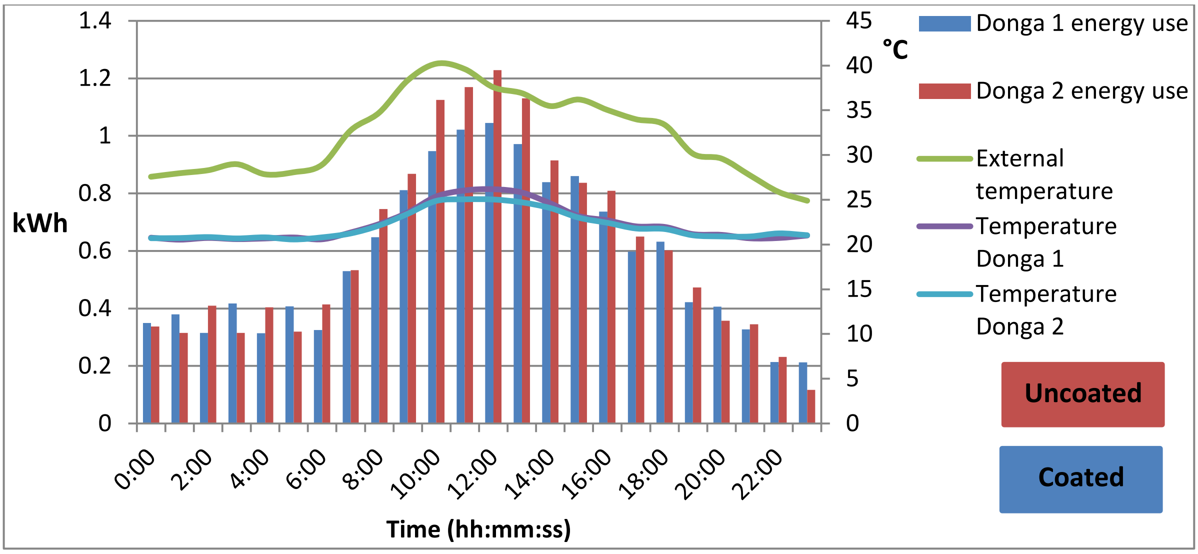

Figure 4.41: Air conditioning energy consumed over hottest recorded day

Notes for figures 4.38 to 4.41:

- The external temperature curve represents the average temperature throughout each of the days recorded.
- The bar chart represents the total energy consumption for the whole day.

The air-conditioning was turned off for a short period and to compare the thermal performance of the two dongas as shown in figure 4.42:

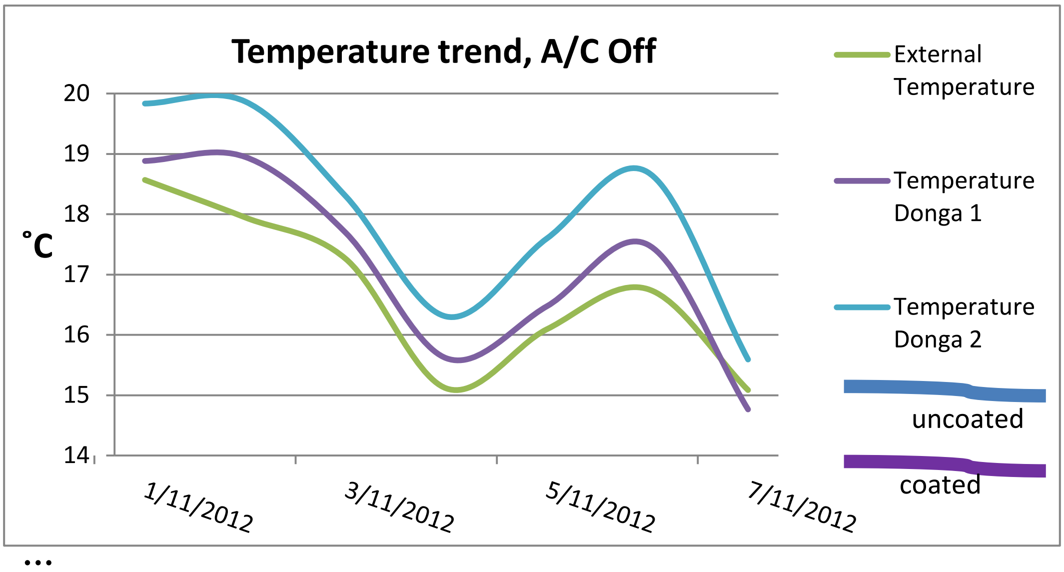

Figure 4.42: Room temperature compared to ambient temperature

4.3.1.2 Behaviour change measures

Programs to achieve behaviour change in communities are commonly practiced by utilities and governments using a community based social marketing methodology for best results (McKenzie-Mohr, 1999). Discussion and development of a methodology to introduce staff to new technologies and systems that might affect their amenity is essential and needs to follow the introduction of any technology or operational system change. This process will promote the removal of barriers to change, not only to implement the change but to maintain it in a cost-effective and socially acceptable way (*ibid*: 19). The significance of social acceptance is woven into the technology development (Oslislo, 2010: 2).

Table 4.19 above includes a limited number of behavioural change possibilities together with an estimated carbon emission reduction effect. The potential to increase these ‘low hanging fruit’ reduction measures is dependent upon several factors, but primarily commitment to ecologically sustainable development and village ownership which can be led by the camp owners and those responsible for its operation. As these are rarely one and the same this commitment is generally exposed as minimal due to the devolved responsibilities.

4.3.2 Carbon emissions reduction by substituting fossil fuel energy with renewable energy

Having established the carbon footprint of MMG, and deducted from that total an estimated amount for energy efficiency and behaviour change (table 4.20 above) there remain further emissions to be accounted for on the path towards achieving carbon neutrality. This reduction can be offered by the introduction of appropriate and sustainable RE system(s).

Two renewable energy systems were assessed and found appropriate for consideration at MMG: fixed array solar photovoltaic (PV) and wind power, both with low-cycle diesel generation backup. The generator incorporated a small battery bank to cover the transition whilst switching from RE and to diesel power generation and visa-versa. A Net Present Cost analysis follows in section 4.4.2 below.

From section 4.1.3 above the operational energy emissions from fossil fuel generation have been calculated to be 583 tonnes $CO_{2\text{-}e}$ per annum for MMG. Two possible RE connection scenarios are possible in order to reduce these emissions:

(i) Retrofitted to the current mine site power generation system.
(ii) As a standalone system.

Both grid connected and standalone systems are dealt with in detail in section 4.4 below.

4.4 Research Q4

What is the appropriate renewable energy technology choice for MMG and what configuration will offset the stationary energy required for operation on a daily basis? How does renewable energy impact the overall carbon account in both standalone and mine site grid connected configurations?

The introduction of RE at MMG is an obvious solution to reducing its carbon footprint. The following section is an investigation into the most appropriate and sustainable RE system, or combination of systems, appropriate for installation at the village. The technology choice is based on a model of sustainability by applying modelling tools HOMER and REMAX for standalone and grid connected systems respectively, followed by a financial analysis. An appropriate RE selection has to be made for MMG before its impact can be assessed in both configurations. This section deals with alternative configurations for RE designed to offset the calculated operational energy emissions of the village first retrofitted to the existing generation setup, essentially a grid connected system, and secondly a standalone system.

4.4.1 Standalone Technology choice and configuration

Investigation reveals that there are no mine site villages existing that are powered solely by RE. However, this research indicates that such systems could be sustainable when planning new mine site villages dependent but conditional upon two factors:

i. Projected life span of the mine and residential village.
ii. Distance of the proposed village from the mine.

The analysis shows that wind and solar PV are the best options to consider. A standalone RE analysis, modelled using HOMER (Hybrid Optimization of Multiple Energy Resources) [see see section 3.4.3 (iv) and Appendix 8], to offset a proportion of the emissions from operational energy use, shows that the actual percentage of RE penetration (substitution of diesel and gas fuels) varies according to the size of the system and the period over which the system is likely to be used (table 4.21 below). Clearly, the larger the RE system the greater the amount of carbon emissions it would reduce the fossil-fuel footprint by – less obvious is how the life span of the village, and therefore the RE system, affects the overall cost and extent of carbon reduction. The modelling results in this table show that the penetration of RE is not linear and that for a project starting in 2018 during the first two years there is no justification to use any generation system other than the low-cycle diesel generators. Only after a projected project life of four years is there substantial penetration at 51 percent.

The following table 4.21 when read with the HOMER modelling (Appendix 8) shows that from the sixth year and beyond the selected RE system(s) becomes both financially justifiable and effective in reducing the diesel carbon emissions. Projecting the commencement of the project forward to 2018 takes into account the projected increase in cost of diesel fuel and gas, and the reduced cost of RE.

Project life (Yrs)	Standalone system configuration	Total NPC ($)	Renewable energy penetration (%)	CO2 offset (t/yr)
1	Generators	$676,912.00	0%	0.00
2	Generators	$1,191,611.00	0%	0.00
3	Generators + PV(110kW)*	$1,628,421.00	20%	13.37
4	Generators + FWS**(100kW) x 2	$1,946,472.00	51%	221.62
5	Generators + FWS(100kW) x 3	$2,139,487.00	70%	345.61
6	Generators + FWS(100kW) x 3	$2,307,853.00	70%	345.61
7	Generators + FWS(100kW) x 3	$2,463,467.00	70%	345.61
8	Generators + FWS(100kW) x 3	$2,607,215.00	70%	345.61
9	Generators + FWS(100kW) x 4	$2,721,967.00	83%	422.98
10	Generators + FWS(100kW) x 4	$2,822,253.00	83%	422.98
11	Generators + FWS(100kW) x 4	$2,914,923.00	83%	422.98
12	Generators + FWS(100kW) x 4	$3,000,554.00	83%	422.98
13	Generators + FWS(100kW) x 4	$3,079,784.00	83%	422.98
14	Generators + FWS(100kW) x 4	$3,153,255.00	83%	422.98
15	Generators + FWS(100kW) x 4	$3,221,145.00	83%	422.98
16	Generators + FWS(100kW) x 4	$3,284,260.00	83%	422.98
17	Generators + FWS(100kW) x 4	$3,342,795.00	83%	422.98
18	Generators + FWS(100kW) x 4	$3,396,885.00	83%	422.98

Table 4.21: HOMER output for project commencing 2018. (Ploumis, 2011)

Notes: * = Low cycle diesel
** PV = Solar voltaic panels
** FWS is a trade name of a small wind

Note: The financial viability, and therefore the overall sustainability, of RE system generation of energy at the MMG village, is as significant a factor as is the potential for reduction in GHG emissions. The columns labelled "RE penetration" and "Carbon offset" results will, therefore, be discussed in section 4.4.2.

The first task, prior to applying the modelling, is to view the predicted daily energy consumption at MMG under summer and winter conditions. BEC Engineering Ltd supplied the following energy consumption profile from which hourly load profiles can be extrapolated and compared to the real time monitoring data.

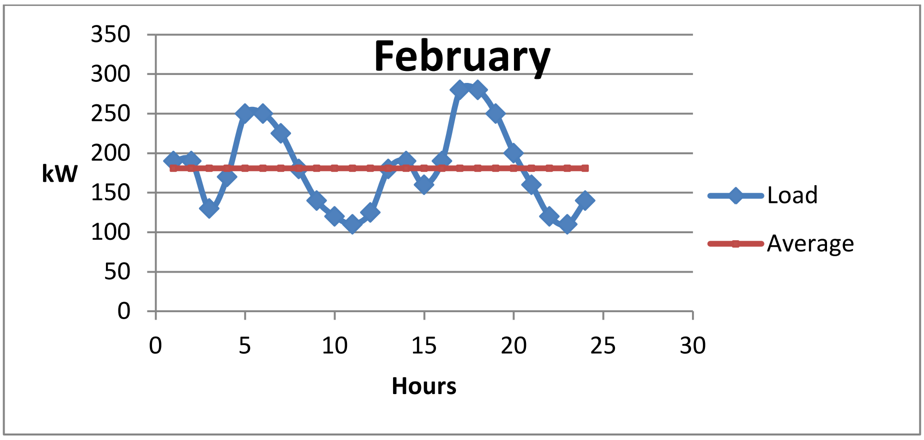

Figure 4.43: MMG village Daily Electricity use for February (summer) (BEC Engineering, 2011)

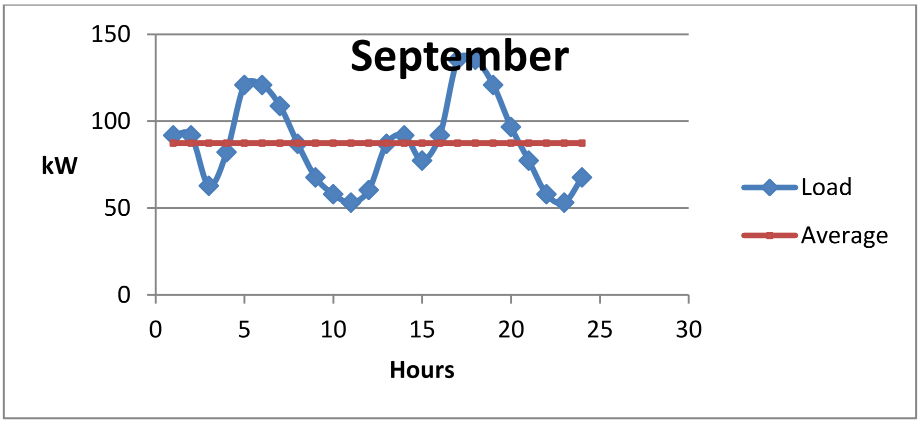

Figure 4.44: MMG village Daily Electricity use for September (winter) (BEC Engineering, 2011)

HOMER modelling makes hourly energy balance calculations over a period of 12 months by comparing the village's load demand (figures 4.43 & 4.44) with potential output of a variety of RE systems over that period. A variety of sizes of PV, wind turbines, and inverters were analysed in order to identify the most appropriate system. HOMER also modelled the most appropriate diesel generator(s) for load smoothing and backup, concluding in the case of MMG Village, that a combination of low-load generators with a total output of 250kW with three output options: 50, 100 and 150kW. The 50kW generator is the most economical to run and retains its efficiency to cover any small load fluctuations that may occur. Which technology, or combination thereof, provides the optimum sustainable power generation for MMG Village can be deduced from the modelling. The output summary in table 4.21 indicates a mix of wind turbines and low-cycle low-load diesel generators as being the optimum standalone configurations dependent on the anticipated life span of the village.

According to the Bureau of Meteorology the average annual wind speed at Mt Magnet, 10m above ground level, is 4.465 m/s and can be seen represented in figure 4.45.

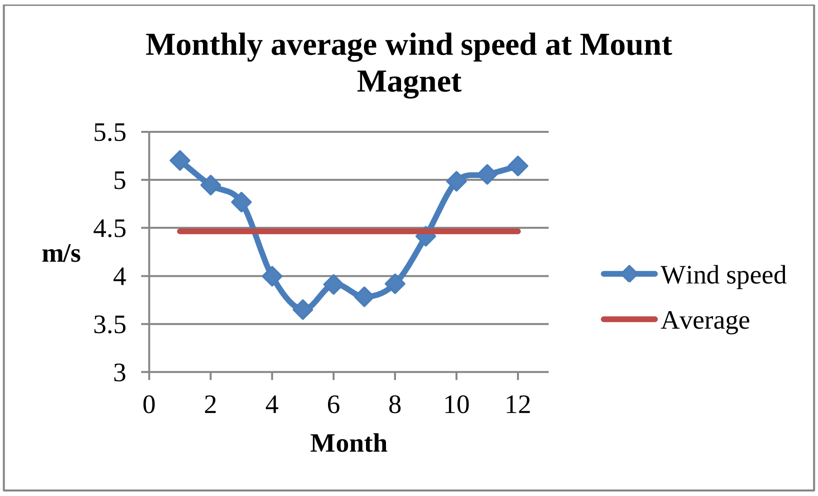

Figure 4.45: Monthly average wind speed seasonal variation (BoM, 2011)

Utilising the BoM analyses of the wind resource at 10m above ground level, namely; frequency distribution; cumulative probability; and a Weibull distribution factor estimation, an accurate assessment of wind as a predictable and harvestable RE system can be made. The complete analysis is covered in the Appendices 8 and 9. Analysis shows that harvesting wind at MMG Village is a feasible and valuable exercise. The BoM wind rose in figure 4.46 supports this.

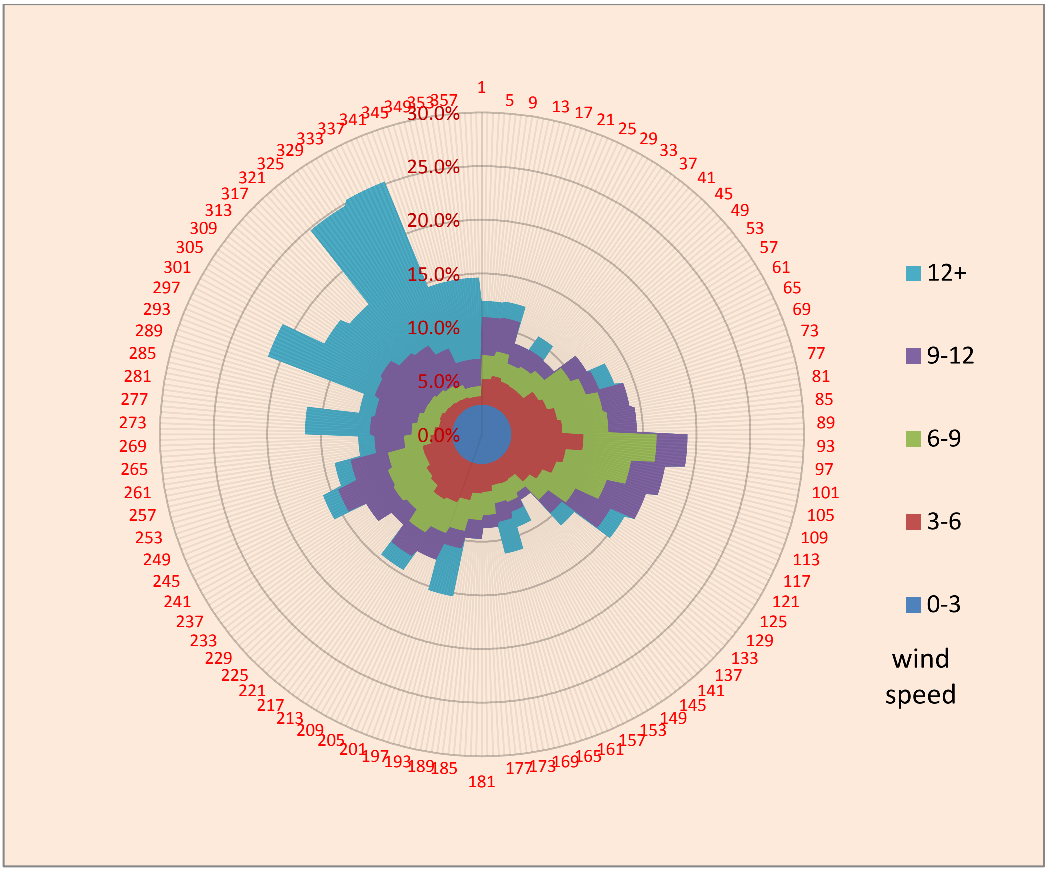

Figure 4.46: Annual average wind speeds 10m above ground level (BoM, 2011)

Several stakeholders would ultimately be involved in the decision-making process of technology selection. For the identified stakeholders in table 4.22 and for the selected social, environmental and economic criteria summary see table 4.23 with the final MCA results in table 4.24 (for MCA analysis see Appendix 10).

Identified Stakeholders
Head office MMG village employee MMG village resident MM community (resident)

Table 4.22: MMG village RE power system project stakeholders

Social	Environmental	Economic	Technical
Education on use Health and safety Employment Social acceptability Social benefits	Materials Energy use Biodiversity Emissions Compliance Land use Aesthetic	Capital cost Operating cost	Efficiency Reliability Degree of maintenance required Maturity Implementation duration

Table 4.23: Social, Environmental and Economic Criteria for RE power system

(Hardisty P, 2010 and Wang J. *et al.*, 2009)

Option	Total rating	Rank
PV	3.8146	1
Wind	3.8112	2
Concentrated PV	3.2529	3
Solar Thermal	3.2254	4
Biomass	3.2110	5

Table 4.24: Multi-criteria analysis result (see Appendix 9)

(Ploumis, 2011)

HOMER analysis clearly indicates an overlap between PV and wind systems, and although the NPC analysis leans towards wind energy the two technologies complement each other, even if it is a well worn cliché "when the sun doesn't shine or the wind doesn't blow." PV was selected as the best RE to avoid any potential noise pollution from wind turbines set close to the village.

4.4.2 Grid connected RE

This section deals with the viability of a grid connected system retrofitted to the existing power generation system some distance from MMG at the mine site itself. A new modelling tool, dubbed REMAX was developed to cover the situation where HOMER could not be used for the modelling in grid connected situations, particularly where the grid generation is fuelled by a mix of fuels.

MMG's operational energy represents only a small proportion (2.46%) of the energy consumed by both mining operations and the village (see figure 4.29). The generation sensitivity of the power plant to fluctuations in load is between 50kW and 100 kW [4]. Load fluctuations in the village were monitored as being significantly less than 50kW and as such would not affect the overall energy being generated at the mine site to which it is connected as it operates at a constant rotational speed. To have an effect the generation plant would need to be capable to respond to load fluctuations of 100 kW or less, which is described herein as an 'ideal' system. Any RE system retrofitted to the current power system, appropriately sized to have the output and energy generation capacity equivalent to the operational requirements of the village, would not have an impact on the mine site generation system to which it is connected. The consequence of this is that no fuel would be saved at the generation plant by introducing RE and, therefore, no carbon emission reduction from doing so. Furthermore, there would be no financial benefit.

However, if the current power generation system is modelled as being 'ideally' responsive to small loads then the analysis provides a different result. REMAX analysis indicates that, following an NPC analysis, to offset the operational energy of MMG the optimum RE retrofitted configurations would be a 250 kW fixed PV array plus 1 x 50kW wind turbine. For this configuration a further NPC analysis was done for the years 2014 and 2018 and for three orders of generation systems; the current power system at the mine site with 'ideal' response to load; the current power system (ideal) plus RE; and, the current power system at 80% of 'ideal.,' The analyses are represented in figures 4.47 and 4.48 below.

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[4] According to Engen Ltd who lease the system to RMS

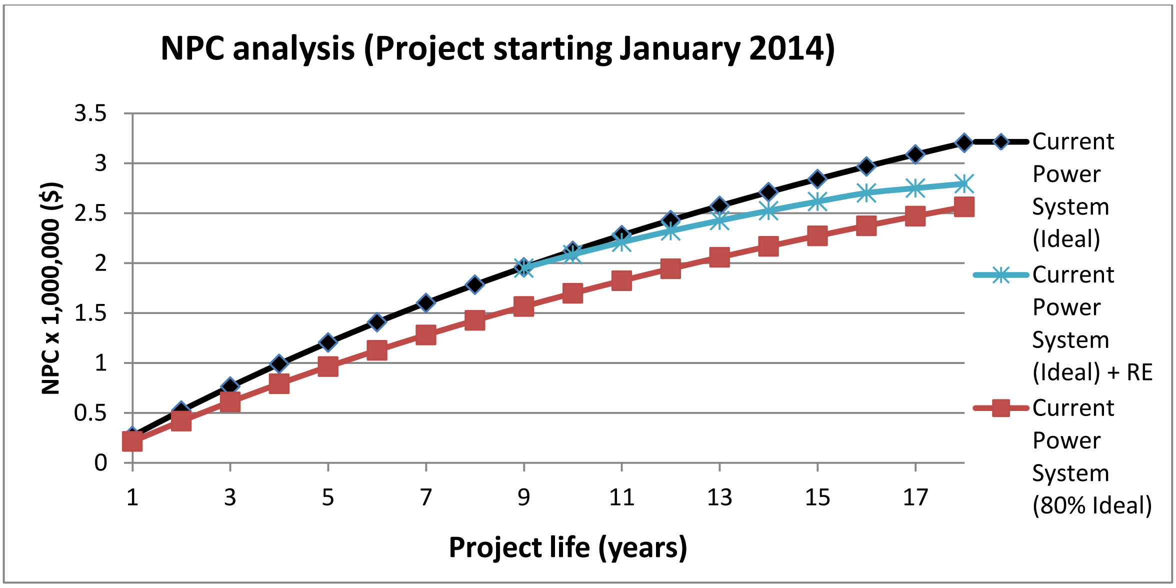

Figure 4.47: NPC analysis three power generation system configurations for project commencing in 2014 (Ploumis, 2011)

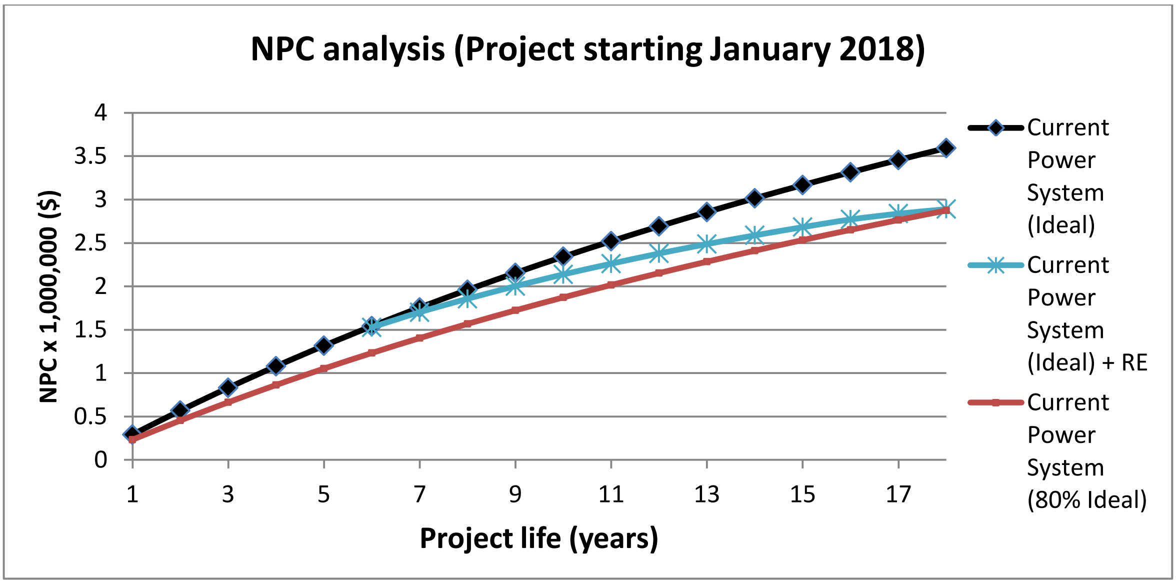

Figure 4.48: NPC analysis three power generation system configurations for project commencing in 2018 (Ploumis, 2011)

The graphs indicate that for a project commencing in 2014 there would be no financial justification to retrofit to the current mine site generation system an RE system to offset MMG’s operational energy until year nine. Projected to commencement in 2018, with reduced cost of RE and increased cost of diesel and gas a project life of six years or more would provide a financial benefit if the system could respond ‘ideally’. To respond ideally the mine site generation system would require adaptation to justify the RE retrofit by the introduction of a turbine responsive to the village’s small loads such as two 250 kW low cycle generators dedicated to village energy supply. Larger villages would produce load fluctuations substantially greater than at MMG and may well be large enough for the mine site generators to respond ideally. In this case the retrofit of RE would likely be justifiable without modification thus reducing fossil fuel consumption with commensurate reduction in carbon emissions and cost.

4.5 Research Q5

What are the financial, technical and sustainability implications for standalone village power system power including the removal of the power supply line from the mine generating plant several kilometres away and does this distance have any material significance?

The distance of the proposed village from the mine can also be taken into consideration when evaluating the viability of standalone power generation. The villages are always sited remotely from the mine site operations and its generation plant primarily for occupational health reasons, to avoid dust and noise pollution. Depending on ground conditions research has shown that a 22 kV 3-phase transmission line connecting the two would cost at least $200,000 per kilometre. Removing the requirement to construct this line would significantly reduce the CAPEX to provide power to the village and, therefore, it could be offset against the cost of the RE system(s). Figure 4.48 below clearly shows that if the distance between the mine site power plant and the village is over 4 km and the life of the project is 7 years or more, a standalone system is economically viable, irrespective of the added factor of substantial carbon emission reduction which is illustrated in figure 4.49 below.

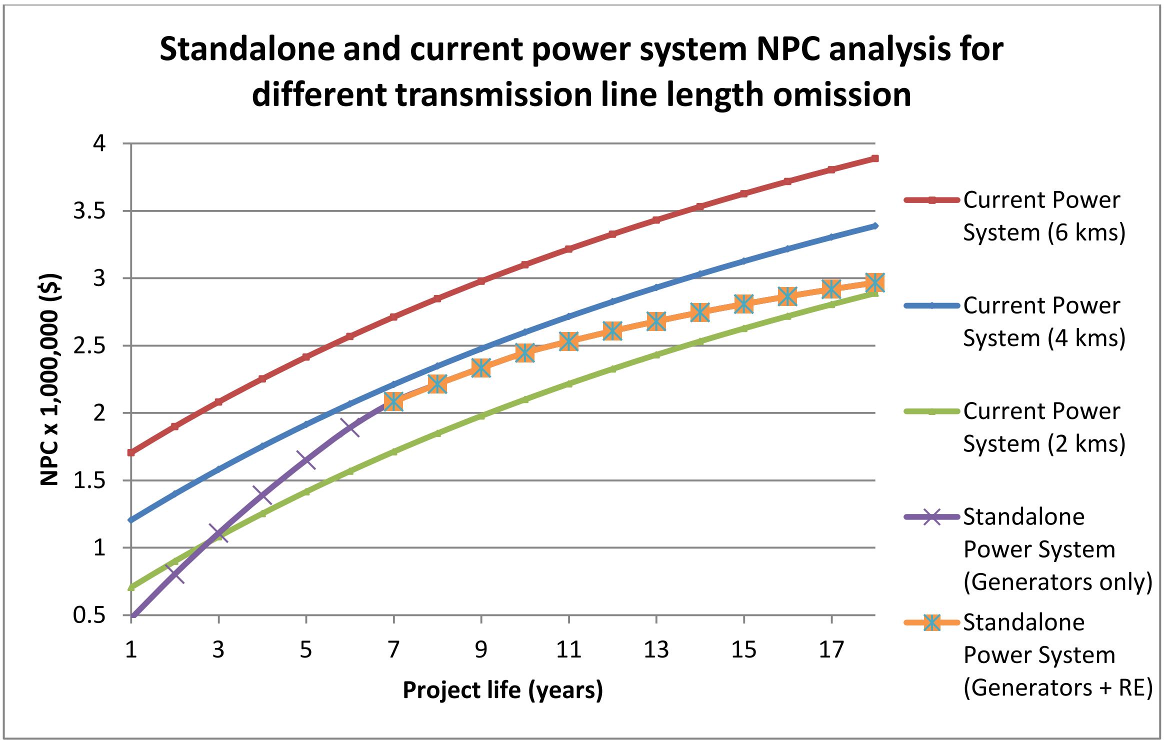

Figure 4.49: Cost comparison of standalone power over time to include potential omission of transmission lines distances of 2, 4 & 6 km in length.

(Ploumis, 2011)

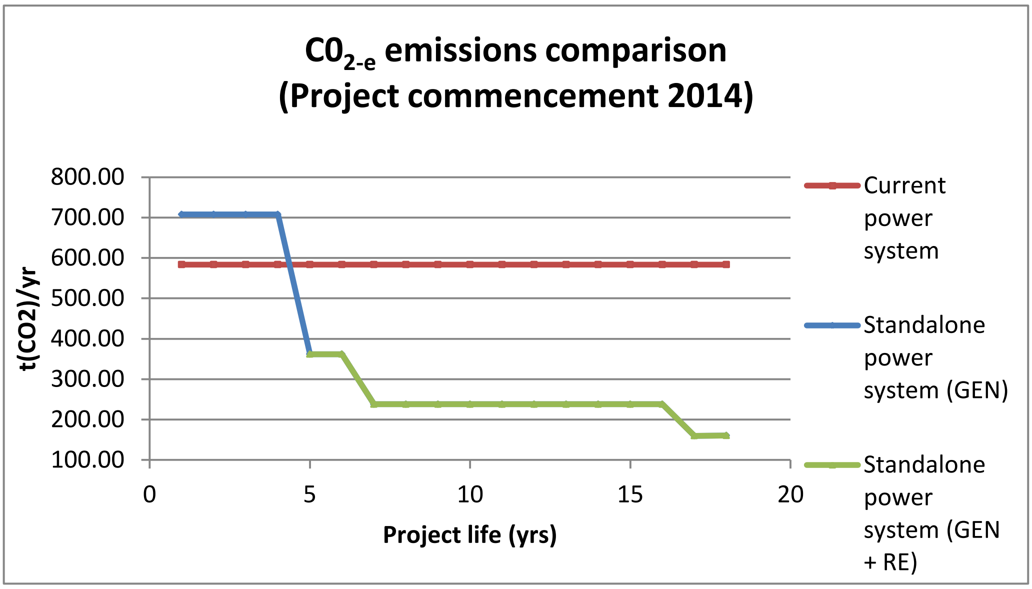

Figure 4.50: Carbon emission comparison of standalone systems with the current p system for project commencing in 2014

(Ploumis, 2011)

It should be noted that figure 4.50 does not include the reduction in emissions equivalent to the embodied energy of the transmission line or the addition of the embodied energy of the RE system itself.

Referring back to table 4.21, the HOMER output for a project commencing in 2018, the generators referred to are three low cycle generators of 150kW + 100kW +50kW capacity. The three sizes are significant in that they respond to the loads applied more efficiently than if only the larger size generators were installed. The appropriately sized generator runs in response to the load it is called upon to generate. These generators run extremely efficiently as they can operate at a very low percentage of their potential output (down to 5% of load) without losing significant efficiency. This not only saves considerable diesel fuel but reduces maintenance. Minimal battery storage capacity is included with the generator setup to provide power for the very short time as generators start up.

Figure 4.50, compiled from table 4.21, shows that RE system(s) by year 4 show a reduction of carbon emissions below the current power system, and by year 3 when projecting the commencement of the project to 2018, as in figure 4.51.

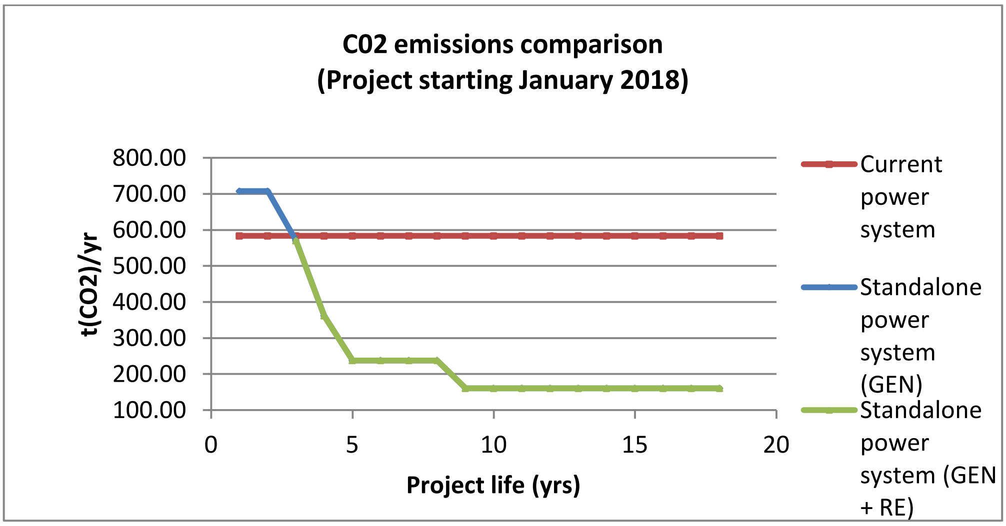

Figure 4.51: Carbon emission comparison of standalone and power systems with the

current power system for project commencing in 2018 (Ploumis, 2011)

4.6 Research Q6

What are the financial implications of the various carbon reduction methods and how does the purchase of carbon offsets complete the carbon neutral emissions account?

MMG's carbon footprint has been established. The final piece in the puzzle, how to convert a fossil fuelled mine site village into one which could be described as carbon neutral, remains. One solution is the purchase of carbon offsets to account for the emissions that have not been reduced by other means. This can be done in several ways which are internationally accredited, such as forestry or carbon credits from large RE systems. Furthermore, when considering sustainability consideration should be given to the proportion of the carbon footprint that it is appropriate to purchase.

Although the calculation of carbon emission reduction has formed a substantial proportion of the thesis, finance must come in for consideration in assessment of sustainability. Several scenarios of carbon reduction at MMG have been dealt with in some detail and are now evaluated in terms of cost and simple payback. These are:

(i) Cost of offset purchases following deduction of energy efficiency + behaviour change + renewable energy.
(ii) Cost of carbon reduction from energy efficiency, behaviour change and tree planting.
(iii) Cost of energy efficiency and behaviour change reduction, renewable energy and tree planting (for project commencing 2018).
(iv) Cost of offset of MMG carbon footprint by large solar PV only.

4.6.1 Cost of Offset purchases following emissions deduction of energy efficiency + behaviour change + RE

Following deduction of the estimated reductive capacity of the combination of energy efficiency and behaviour change from MMG's carbon footprint the RE offset of the operational energy emissions can now be applied to what remains, that is:

Carbon footprint – (energy efficiency + behaviour change) – RE reduction = Remainder to be offset by accredited carbon purchases

The RE system capacity to reduce emissions was found to be dependent on three main factors: year of installation; whether grid connected or standalone; and the projected life span of the village beyond date of installation. In accordance with the above formula, for a project commencing in 2018, table 4.25 shows the remainder of the calculated carbon emissions of MMG to be offset after deduction of energy efficiency, behaviour change and standalone RE.

Life span of Village	**Emissions per annum (E)**	**Est. energy efficiency (EE) + behaviour change (BC) reduction per annum (a)**	**Balance of carbon after EE & BC reduction**	**Operational energy emission offset p.a. using standalone RE (b)**	**Total reduction from EE + BC + RE**	**Balance of carbon to be offset by purchasing offsets = E - (a+b)**	**Overall reduction of EE+BC+ RE**
	(tonnes CO_{2-e})						**(% p.a.)**
20 years	2424	281	2143	423	704	**1720**	29.0
15 years	2513	281	2232	346	627	**1886**	25.0
10 years	2690	281	2409	346	627	**2063**	23.3
5 years	3223	281	2942	222	503	**2720**	15.6

Table 4.25: Calculation of MMG carbon emissions remaining after energy efficiency and behaviour change plus RE emissions reduction, for project commencing in 2018

The significance of this table is that it reveals, even after deducting the sum of the energy efficiency and behaviour change measures, and adding the carbon offset potential of RE (offset against the emissions from the stationery energy) there still remains a large percentage of the overall annual carbon emissions of MMG to be offset *en route* to carbon neutrality. For example, in the case of a projected lifespan of the village of 20 years some 71% of the annual carbon footprint remains to be purchased in this manner, rising to 84.4% for a 5 year lifespan. The cost of offsetting this final balance is set out in table 4.26 below using a median price for purchasing forestry carbon of $22.50/tonne CO_{2-e} and shows this according to the four considered life spans of the village. Recent purchases of carbon credits in Australia are currently being offered in the open market for $14.40/ tonne CO_{2-e} (Clean Energy Regulator, 2015).

Apart from purchasing trees there many alternatives in the market that can provide a carbon offset solution, such as carbon credits from wind farms and methane extraction from landfill sites. The cost of these alternatives varies considerably so the purchase of carbon credits from tree plantation is only considered here.

	5 years	**10 years**	**15 years**	**20 years**
Balance of emissions after EE+BC+RE reduction *(from table 4.25)* **(tonnes CO $_{2-e}$/annum)**	2720	2063	1886	1720
Cost per year in trees for carbon neutrality (after deduction of EE + BC + RE) ($)	61,200/a	46,417/a	42,435/a	38,700/a
Cost of tree planting over the full project life (after deduction of EE + BC + RE) ($)	**306,000**	**464,170**	**636,525**	**774,000**
Cost of tree planting to offset full footprint (zero deduction for EE, BC, RE) ($)	**360,000**	**610,000**	**860,000**	**1,090,000**

Table 4.26: Comparison cost of purchasing carbon offset from forestry (after deduction of EE, BC & RE from footprint and for offsetting the full carbon footprint)

Note*: Based on sequestrating carbon emissions at $22.50/tonne (Carbon Neutral, 2011)

The cost of rendering the balance of carbon emissions, following reduction of the aggregate of energy efficiency, behaviour change and the operational energy RE, is for a projected village life span of 5 years $306,000 and for a 20 year life span $774,000 , increasing the CAPEX accordingly. To offset MMG's full carbon footprint by planting trees is $360,000 for a 5 year life span and $1,090,000 over a 20 year life span.

4.6.2 Cost of carbon reduction from energy efficiency, behaviour change and tree planting.

Another permutation for bringing about the carbon reduction of MMG's footprint to a point of carbon neutrality is to first of all engage in energy efficiencies and behaviour change methods, then complete the process by purchasing carbon offsets, which in this case is carbon credits from tree plantation.

The introduction of energy efficiency and behaviour change has been quantified in terms of carbon reduction at a total of 281 tonnes CO_{2-e} per annum and table 4.27 shows an estimated costing. These costs represent an estimate of a single setup and replacement cost where anticipated, for example in the laundry where machines are only likely to have a 5 year life.

Reduction Method	Detail	Estimated cost	Yrs	Annual cost ($)
1. **Energy efficiency:**				
i. Modified building construction design.	Passive solar village design, improved insulation, shade structures, additional solar water heating.	$250,000	5	50,000
			10	25,000
			15	17,000
			20	12,500
ii. Smart control	Integrated BMS.	$50,000	5	10,000
			10	5,000
			15	3,300
			20	2,500

iii. Laundry modification	Energy efficient appliances	$10,000	5	2,000
			10	2,000
			15	2,000
			20	2,000
iv. Roster change (→flight number reduction)	From 8 days On 4 Off to 10 On 5 Off	56 flights/annum 48 (Saving $15,000) *****	5	(15,000)
			10	(15,000)
			15	(15,000)
			20	(15,000)
v. Grey water reuse of residential waste water	Reduces ½ vol. water to treat in WWTP	$40,000	5	8,000
			10	4,000
			15	2,600
			20	2,000
2. Behaviour Change:				
i. Water use - desalination ii. Waste water - treatment	Education in water management and conservation, and energy efficiency	$5,000 p. a.		
iii. General awareness	Training program for energy efficiency and behaviour change		5	5,000
			10	5,000
			15	5,000
			20	5,000
		Overall annual cost	**5**	**$60,000**
			10	**6,000**
			15	**14,900**
			20	**9,000**

Table 4.27: Estimated annual cost of energy efficiency and behaviour change program

Using the figures in table 4.27, a table of overall cost can be drawn for tree planting to offset the balance of carbon post EE and BC reduction - see table 4.28.

	5 years	**10 years**	**15 years**	**20 years**
MMG Carbon Emission remaining after EE, BC reduction (tonnes CO $_{2-e}$/annum) *(from table 4.25)*	2,942	2,406	2,232	2,143
Energy efficiency opportunities & Behaviour change CAPEX ($/a) *(from table 4.27)*	60,000	26,000	14,900	9,000
Cost per year in trees for carbon neutrality (after deduction of EE + BC) ($/a)	66,195	54,135	50,220	48,218
Cost of EE + BC + trees/annum ($)	126,195	80,135	65,120	57,218
Cost over full project life ($)	**630,975**	**801,350**	**976,800**	**1,144,360**

Table 4.28: Overall cost of energy efficiency, behaviour change and tree planting

4.6.3 Cost of energy efficiency and behaviour change reduction, renewable energy and tree planting (for project commencing 2018).

The cost of energy efficiency and behaviour change plus renewable energy (wind and PV) can be calculated from previous tables as set out in Table 4.29 below.

	5 years	**10 years**	**15 years**	**20 years**
	million $/a			
Energy efficiency opportunities & Behaviour change CAPEX ($/a) *(from table 4.27)*	0.06	0.026	0.015	0.009
Life time cost of EE + BC	0.30	0.26	0.23	0.18
Annual balance of carbon to be offset by tree planting **(tonnes CO $_{2-e}$)** *(from table 4.26)*	2720	2063	1886	1720
Annual cost tree planting *(from table 26)*	0.061	0.046	0.042	0.039
Life time cost of tree planting	0.31	0.46	0.64	0.77
Life time cost of RE offset	2.14	2.82	3.22	3.41
Overall cost of EE+BC+RE+ offset purchase	**2.75**	**3.54**	**4.09**	**4.36**

Table 4.29: Overall cost of energy efficiency, behaviour change, renewable energy and tree planting

4.6.4 Offset of MMG carbon footprint by large fixed solar PV only

A further solution for RE to render MMG carbon neutral is to substantially increase the delivery of RE well beyond that required to merely offset the emissions of the operational energy component of the carbon footprint. A basic costing for the installation of a 2.5 to 3MW fixed PV array (size dependent on the projected village life span), has the capacity to offset MMG's full carbon footprint. Table 4.30 also includes a simple payback period from the fuel savings at the mine site generation plant.

It is clear from table 4.30 that the capital expenditure required is considerable and varies according to the anticipated life of the village. Based on the projected cost of large scale fixed array PV in 2018 for a village life span of 5 years is 23% more expensive than that for a 20 year life span. However, there are substantial savings with this format of carbon reduction due to the reduction of diesel and gas fuelled generation. The payback periods are certainly attractive being between 5.7 and 2.6 years for life spans of 5 and 20 years respectively.

	5 years	**10 years**	**15 years**	**20 years**
(i) Overall MMG Carbon Emission (tonnes CO $_{2\text{-e}}$/annum)	3,223	2,690	2,513	2,424
(ii) PV system Capacity required, at MMG latitude (MW)	3.15	2.66	2.50	2.41
(iii) Estimated PV CAPEX (M $)	6.93	5.85	5.49	5.31
(iv) Energy production (GWh/annum)	6.11	5.16	4.84	4.68
(v) Cost saving (million $/annum)	1.21	1.26	1.62	2.08

(vi) Simple payback period (years)	5.72	4.64	3.39	2.55

Table 4.30: Costs and payback for large solar at MMG for project commencing 2018

Explanatory notes for table 4.30

(i) From the carbon account summary of MMG with village life spans of 5, 10, 15 & 20 years, table 4.18.

(ii) Size of fixed PV array to offset MMG's full carbon footprint.

(iii) Cost of PV array

(iv) Energy produced by PV array.

(v) Cost of diesel and LNG to produce equivalent supplied by PV.

(vi) CAPEX/saving.

4.6.4.1 Example of workings for PV sizing

The PV system sized to offset MMG's full carbon footprint, for a village life span of 5 years, is capable of generating energy of 6.11GWh/annum., which would otherwise be generated by the mine site fossil fuelled plant in the ratio of 19:81 diesel:LNG

= 6.11 x 19% fuelled by diesel
6.11 x 81% fuelled by LNG

= 1.1609 GWh by diesel power

4.9491 GWh by LNG power

As 0.2683 litres of diesel and 0.2106 litres of LNG each produce 1kWh of energy, taking into average losses (BEC Engineering, 2012), the fuel saved by generating the 6.11 GWh/annum by large scale fixed array PV

= $1.1609 \times 10^6 \times 0.2683 = 311{,}443$ litres diesel/annum

$4.9491 \times 10^6 \times 0.2106 = 1{,}042{,}280$ litres LNG/annum

Average cost of diesel over life span = \$1.45/L

Average cost of LNG over life span = \$ 0.65

Therefore, cost savings = 311,443 x \$1.55 = \$482,736 in diesel and 1,042,280 x 0.70 = 729,596 = approx. total savings of million \$1.13.

This calculation is repeated for the remaining village life spans for the PV array output required to offset MMG's full carbon footprint and included in table 4.30 above. A 5 percent per annum increase in the cost of both diesel and LNG has been factored in.

Once the capital expenditure for the large PV installation is repaid the array will continue to be a substitute for diesel and gas fuelled energy generation and begins to save expense for the stakeholder. Table 4.31 sets out this earning capacity for the remainder of the projected life span of the village.

	5 years	**10 years**	**15 years**	**20 years**
Payback period	5.72	4.64	3.39	2.55
Years of saving during period	0	5.36	11.61	17.45
Saving **capacity** over period (million $/annum)	0	1.26	1.62	2.08
Saving **potential** over period (million $)	0	6.75	18.81	36.30

Table 4.31: Earning capacity of large PV array at MMG

4.7 Research Q7

Is the carbon neutral mine site village a viable proposition, or merely a desirable objective in the context of sustainable development of the built environment?

The answer to this is based, to a large extent, on a subjective view of whether the results of the previous six research questions when drawn together, constitute a sustainable solution in the context of this thesis. Furthermore, what is regarded by one stakeholder as sustainable is not necessarily the view of another. The question is discussed in discussion chapter 5 in more detail.

4.7.1 Drawing the results together

A cost comparison of the methods to achieve a carbon neutral MMG is shown in table 4.32:

Cost combination		5 years	10 years	15 years	20 years
		(million $)			
EE + BC + tree planting *(table 4.28)*	Annual	0.13	0.08	0.07	0.06
	Lifetime	0.63	0.80	0.98	1.44
EE + BC + RE* + tree planting (table 4.29)	Annual	0.55	0.35	0.27	0.22
	Lifetime	2.75	3.54	4.09	4.36
RE (large fixed array PV) **	Annual	See table 4.30 for cost benefit			
	Lifetime				
Tree planting *** (full MMG footprint) (table 4.26)	Annual	0.073	0.061	0.058	0.055
	Lifetime	0.36	0.61	0.86	1.09

Table 4.32 Cost comparison of selected methods to achieve carbon neutral MMG

Notes: * RE systems in this combination are sized and costed to reduce only the operational energy element of the carbon footprint.

** Large PV array CAPEX to offset the full footprint spread evenly over the life span. The earning capacity of the array, once the savings are equivalent to the CAPEX, are set out in table 4.31.

*** Tree planting at $22.50/ tonne CO_{2-e} to offset the full MMG footprint.

Table 4.32 reveals:

- That the least costly method to offset the full carbon footprint is to purchase accredited forestry.
- With reference to table 4.30 that the installation of a large fixed PV array has a significant cost benefit as well as reducing MMG’s carbon footprint to zero.

In addition to the cost comparisons of these carbon reduction methods a financial summary of the solutions for a carbon neutral MMG, leaving aside the construction of a large PV array, it becomes apparent that:

- For short village life spans (up to 15 years) the most affordable method is merely to purchase accredited carbon offsets such as planting trees.
- Standalone RE, when sized to offset only the operational energy consumed by the village, does not present an economic solution.

If a large fixed PV array installation is considered, sized specifically to offset MMG's full carbon footprint, although requiring a substantial capital outlay, with a village life of 5 years or longer is capable of earning the stakeholder substantial returns.

4.8 Research Q8

Are the metrics produced by the overall results applicable to model future carbon neutral villages of similar construction?

The individual sources of carbon emissions a building, group of buildings or a precinct are responsible for are set out in figure 1.2. A generic modelling tool described as LEVI (Low Energy Village Infrastructure) - see Appendix 10, was developed in the form of an Excel workbook to guide and provide a means to calculate each emission source. The methods calculation therein can be applied to all building formats with increasing degrees of complexity according to the variety of building types and forms included.

Chapter 5 – Discussion

5. DISCUSSION

The central theme of this thesis is carbon emission reduction in the built environment and how to determine a means whereby it could be considered that a building or group of building could sustainably reduce the carbon emissions it is responsible for, its carbon footprint, to a point where it could be justifiably described as 'carbon neutral.'

This chapter will discuss the following:

i. The quality, assumptions and limitations of the results and answers to the research questions.
ii. Comparison with previous work in the field.
iii. The application of the MMG case study on a broader scale.
iv. The contribution of the thesis to research in the area.

The quality, assumptions and limitations of the answers to the research questions

A conceptual model for low energy village infrastructure development was developed, termed as LEVI©, and is set out in appendix 10. Constraints and influences upon the carbon neutral development model in the box at the top of this model indicate variables that affect the calculations:

(i) The life of the village - the anticipated life of the village. This would have been determined at the outset by the mine owners according to their view of the length of time of the viability of the resource to be mined and its profitability for the enterprise. Commodity markets are extremely volatile and will likely affect judgement of the potential life of the operation and, therefore, the need for village accommodation over that period to support the mining operation. The viability of MMG is certainly dependent upon the profitability of RMS' mining operations which in turn is governed by the cost of resource extraction and the financial return of the sale of the gold. Observations of current trends indicate that MMG has a short term viability of no more than 10 years.

(ii) Cost and budget – the cost to the company of low carbon development and the budget for its construction will certainly affect the take up of carbon reduction solutions. The requirements of legislation relating to carbon emissions in Australia have fluctuated dramatically in recent times and this has accordingly had an impact on the imperative to reduce, particularly amongst heavy polluters.

(iii) Commitment to ecologically sustainable development (ESD) - if the camp is operated by those other than the mining company the commitment to carbon reduction may be greater, but due to the cost involved is more than likely to be the opposite.

(iv) Cost of carbon – The carbon tax legislation in Australia has recently been repealed and much of the incentive to reduce an enterprise's carbon emissions no longer exists. It has been left to the market to develop ways of abating carbon emissions and bid by way of reverse auction for carbon polluters to be able to purchase the abatement according to the a price offered at auction.

(v) Size of village or camp – the larger the village the greater the carbon footprint and scope for reduction.

(vi) Village location - the village location is likely to affect the solutions. The solutions to reduce carbon in a coastal, grid connected village will be very different to those for an inland off-grid remote village. Access to a gas pipeline will also have an influence on the carbon emissions to generate electricity.

Having established these constraints and influences the answers to the research questions given in chapter 4 can be discussed. The major components of the carbon emissions calculation of constructing and operating a mine site village such as MMG can be reviewed in figure 1.2; each section is discussed below under the heading of the relevant research question.

In section 3.12 under the Life Cycle Analysis the significance of establishing boundaries of the LCA at the outset of carbon accounting is discussed. The constituents of all carbon footprints are as extensive as the LCA determines and set according to the model tool(s) used.

The following sections critique the calculation of the components of the carbon emission calculations as it refers directly to the case study of MMG. The calculation was based upon 100 percent occupancy of the village and set at 162 residents on a rolling roster of 8 days living on and 5 days off. The number of residents was more or less constant and enabled an annual carbon footprint to be apportioned to each individual worker once the overall footprint had been established.

The calculation and results of the carbon footprint are discussed below followed by way of comments upon the answers to the research questions.

5.1 Research Q1.

What are the constituents of the MMG carbon footprint and how are they calculated?

Discussion of the calculation of the components of the carbon footprint follows.

5.1.1 Embodied energy calculation

The embodied energy of a building is dependent on completing a life cycle analysis of its components and, depending upon where the boundaries of the LCA are drawn, can include external services and infrastructure. Once established the embodied energy figure can be divided by the estimated life span the buildings to give the effective annual carbon footprint for that period. For the purpose of this research the life spans for MMG was set at 5, 10, 15, and 20 years. For building precinct formats, such as a group of residential holiday homes, retirement homes, commercial buildings or a complete suburb, the life span of the whole becomes increasingly complex as the number of different types of buildings increases and the servicing infrastructure and support systems vary. In these cases would be necessary to assess each generic building form individually but the format set by the MMG calculation can certainly be followed.

The principal modelling tool used in this research for the calculation of the embodied energy of MMG was a peer reviewed tool known as eTool™. This tool complies with the requirements of international life cycle analysis assessment standards. MMG is essentially a gated community where the inputs and outputs responsible for carbon emissions can be identified and determined within fairly well defined boundaries. The results for the embodied energy of MMG were certified by eTool™ staff with a margin of plus or minus 5 percent.

5.1.2 Operational energy calculation

An estimate of the annual energy consumption, the stationery energy, of MMG Village was made by the electrical engineers, Matricon Pty Ltd., prior to construction in order to incorporate the appropriate electrical infrastructure and machinery to run the camp. This was estimated to be 1.09 GWh/annum. As described in methods chapter 2 a comprehensive monitoring system was installed in October 2011 and data of all major power circuits collected for three full years along with water desalination and use. In total some 38 power circuits and 10 water meters were monitored. Once analysed it was found that the actual energy consumption was within 5% of the estimated and the calculation of the resultant carbon emissions well within acceptable parameters. The fuel mix for the production of this energy was disclosed by Engen Ltd, engineers who designed and installed the power plant at the mine site which supplies MMG, to be fuelled by gas and diesel fuel in the ratio of 81:19. This ratio was given in 2011 and may have varied marginally since.

5.1.3 Transport of food and groceries to MMG

The system for delivery of foodstuffs and general supplies was investigated and observed by the author during several site visits conducted during the three year monitoring period. The number and size of the deliveries from Perth central stores could only be based on estimates and the annual fuel consumption calculated accordingly.

5.1.4 Food production

Food production takes many forms so its carbon footprint can only be approximated, as can average human consumption. The amount of food consumed by the occupants of MMG represents the carbon emissions of growing, preparing, packaging, and storing that food and has to be estimated using research data referred to in section 4.1.5. Its transport from Perth warehouse to Mt Magnet has been dealt with in the previous section.

This data is based on average individual consumption and upon a mix of Australian grown and imported food. Site observation at MMG clearly indicates that workers appeared to consume considerably larger portions at mealtime than what would be considered as ‘average’, in large part due to the nature of the work, living conditions and no doubt because they were not paying for it.

In short the estimated carbon emissions from the food delivered to MMG Village are likely to be more than the national averages used to make the calculation due to the higher per capita consumption. There are no studies on the matter but an estimate of 30 percent more would not be unreasonable.

5.1.5 Fly-in/Fly-out travel to MMG

Carbon emissions from Fi/Fo access to work can be significant. The calculation in results section 4.1.6, was based upon full occupancy of MMG Village at 162 persons working on a roster of 8 days on site and 5 days off site flying 600km from Perth to Mt Magnet airport. The fuel for the 5km bus trip to and from the village was not included.

The majority of MMG residents travel from the Perth metropolitan area although between 10 and 20 reside outside Perth and travel in some distance to Perth Airport before they fly to MMG Village, which could increase this element of the carbon footprint by up to 2 percent. A small number of commuters come from the Geraldton Region and visitors to the mine would fly or drive for a single overnight stay at MMG but is unlikely to vary the emissions total more 1 percent.

The carbon emission calculations from air travel are based on an internationally accepted formulae, based on short, medium and long distance haul. Mt Magnet just falls within the medium haul category from the more energy intensive short haul category, where the emissions total would be 20 percent higher.

A change of roster for attendance at the village has been mooted as not only a way of reducing capital costs to fly workers to site but to also reduce the carbon footprint in doing so. Fortescue Metals Group has recently announced that by mid-2015 their mining roster will change from 8 days on, 6 days off to 14 days on and 7 days off. This would have the effect of reducing the annual number of flights (excluding holidays) from 26 to 17 return flights, thus reducing flight charter costs and carbon emission from the flights by over 34 percent.

5.1.6 Waste water treatment and desalination

For the purpose of calculating the village's carbon footprint the energy required to desalinate and distribute water was accounted for within the village operational energy. The waste water treatment plant incorporated an anaerobic process where the methane was vented to the atmosphere. A simple solution to reduce emissions would be to flare the methane periodically. Furthermore, the effluent from the treatment process was pumped to settling ponds. Section 5.3.1 discusses the reduction of up to 50 percent of the volume of waste water produced within the camp dongas by diverting shower and bathroom basin waste to a grey water diversion system. This reduction would also reduce the energy required to treat the waste water. The GHG emissions from the complete process as it stands was predicted and calculated in accordance with the Nation Greenhouse Account Factors, 2014.

As with food consumption anecdotal evidence indicates that water consumption is likely to be higher at MMG than the national residential average resulting consequential rise in emissions for desalination, treatment and disposal 30 percent greater than those estimated and included in the final carbon account.

5.1.7 Solid waste to landfill

The carbon emissions from MMG's mixed waste, disposed of at the company's landfill site was estimated. The volume was determined on site by observation and interrogation of village management during a number of visits to MMG during the research.

5.2 Research Q2.

What is the carbon footprint of MMG, a typical mine site village?

The constituents of MMG's carbon footprint were calculated and tabulated in table 4.18 above where each of the constituent carbon emission was expressed on an annual basis. The only total to vary was that for accommodation and infrastructure (item (i) table 4.18) as this calculation was largely dependent on the projected life span of the village itself where the carbon emissions amortise over time. Table 4.18 shows that as the life span increases the embodied energy annual emissions reduce and the other constituents remain constant for each time period. This, therefore, affects the proportion of the whole carbon footprint that they represent. Furthermore, the individual MMG resident's responsibility for carbon emissions varies accordingly as can seen and figure 4.37.

The graph in figure 4.37 clearly shows that by travelling to a workplace on a fly-in/fly-out basis and living in a typical mine site village that the carbon emissions each worker is responsible for is between 15 and 20 tonnes CO_{2e} per annum, depending upon te life span of the living infrastructure. According to Garnaut (2008) and SMEC (2008), where individual annual emissions are put at between 28 and 14 tonnes CO_{2e} per annum depending on the boundaries of the LCA, a mining job doubles the mineworker's carbon footprint at the very least.

5.3 Research Q3.

What is the extent of carbon reduction when energy efficiency, behaviour change measures and renewable energy are applied and how much do they contribute to reducing MMG's carbon footprint en route to carbon neutrality?

Having established a carbon footprint for MMG the task of reducing it towards a point of carbon neutrality commenced based on the conceptual model. The process began with energy efficiency and behaviour change estimates based on previous research and anecdotal evidence. The extent to which EE and BC were applied in the results was nominal and dependent on individual's response to change, as determined in previous research (FMG, 2008 and RTIO, 2009) largely determined by the cost and convenience to the stakeholders. The carbon reduction amounts were estimated and based upon the reports at 12.5 percent of the operational energy for modification to the materials of construction; a 10 percent reduction for the introduction of smart control systems; and amounts of 2 tonnes and 93 tonnes CO_{2e} per annum for laundry appliance modifications and changes to the fly-in fly-out regime.

5.3.1 Energy efficiency and behaviour change reduction of the carbon footprint

Quantifying carbon reduction of a carbon footprint, by means of introducing energy efficiency measures and adopting behaviour change mechanisms, is by no means an exact science. Energy efficiency measures can be wide and varied and behaviour change adoption dependent upon the individual. Table 4.19 shows examples of both and the degree to which they influence the MMG's carbon account.

The energy efficiency measures predominantly relate to energy efficient construction of the accommodation modules (dongas) and control of their use in terms of air conditioning for heating and cooling. Grey water (GW) reuse has been implemented and tested in a mine camp scenario and is capable of reducing the volume of waste water going to the treatment plant by 50 percent (Milani, 2013). This in turn reduces volume and the energy required to operate the WWTP. The GW can be used to improve the social spaces between the rows of dongas by irrigation of landscaping, thus creating a much more liveable environment as well as providing shade and a cooler microclimate.

Several modifications to standard donga construction were included in the suite of energy efficiency measures detailed in the author's contributions to reports made to Fortescue Metals Group and Rio Tinto Iron Ore (Anda *et al.*, 2007 & 2008). Both mining companies were in the process of determining the feasibility of constructing sustainable mine site village accommodation. Several of the modifications were referred to in meetings with accommodation manufacturers Nomad Building Solutions Ltd and McNally Group Pty Ltd, both of whom have a significant market share in this form of construction in Western Australia. Regrettably the meetings resulted in refusal to test any changes because of budgetary constraints and the potential of disruption to the manufacturing process. Both mining companies preferred not to consider potential increases cost to village installations. However, one experiment was carried out during this research: the testing of the application of a ceramic thermal coating to a typical donga to quantify the reduction in the energy used by air conditioners for cooling, as discussed in section 5.3.1.1 below.

The consumption of water determines the volume required to be desalinated as well as the volume passing to the WWTP, both processes requiring energy with consequential carbon emissions. Changes in attitude towards the use and conservation of water ultimately affect the energy used to desalinate the pumped groundwater and its treatment after use. If the donga becomes more thermally stable the use of air conditioning is likely to reduce.

As regards the quality, or appropriateness, of the calculations in this section, the figures quoted are certainly reasonable, even conservative, in view of the profligate use of energy in mine site village scenarios. An attempt has been made to strike an objective solution as to how much energy efficiency measures and behaviour change can have an impact upon the operational energy of the village and affect its overall carbon account.

5.3.1.1 Ceramic thermal coating experiment

This experiment is described in detail in section 3.4.1.1 and the final report submitted to the client is appended here in Appendix 7.

The energy consumption of the air conditioners was specifically monitored as described in the methods chapter by measuring the current drawn over time. The cumulative total of this figure was then converted mathematically to energy (kWh) using this formula:

$$\frac{\textbf{Cumulative voltage recorded x CT capacity x 240 volts* x power factor** x time (mins)}}{\textbf{333 x 60}}$$

The supply voltage* varied between 220 and 240 volts and the power factor of that supply varied between 0.90 and 0.98**. Taking these variations into account the results would have been accurate between, plus or minus ½ and 1½ percent. The experiment indicated that the application of a 1mm thick coating to the exterior walls and roof reduced the energy used for air conditioning, in cooling mode, by approximately 10 percent. Converted to the fossil fuel used at MMG to power the air conditioning a 10 percent fuel saving is significant in terms of dollars and also in consequential reduced carbon emissions. In the case of MMG an accurate financial and carbon emission savings is difficult to assess because the energy used by air conditioning was not measured specifically across the village. However, a measure of over 550MWh per annum was recorded for the total energy consumption of living spaces and from the energy audit air conditioning was taken to represent 90 percent. A 10 percent saving in the fuel mix of 19 percent diesel and 81 percent LNG consumption to generate 500MWh of energy can be evaluated as follows:

- 0.2683 litres of diesel fuel and 0.2106 litres of LNG each produce 1kWh of energy, taking into account average losses of diesel plant generation (BEC Engineering 2012). Fuel source is divided, as referred to, in the ratio of 19:81 diesel: LNG.
- Air conditioning energy generation for all bedroom units at MMG Village

= 500 x 19% MWh/annum using diesel generation
& 500 x 81% using LNG generation for MMG

= 95 MWh/annum diesel generation
& 405 LNG generation for MMG

Therefore fuel consumption

= 95 x 1000 x 0.2683 litres diesel/annum
& 405 x 1000 x 0.2106 litres LNG/annum
= 25,488 litres diesel/annum
& 85,293 litres LNG/annum

	Cost/L diesel (after fuel subsidy)	**Cost/L LNG**
	$ 1.45	$0.61
25,488 litres diesel	$36,957	
85,293 litres LNG		$52,028
Total fuel cost = $ 88,986/annum		
10% saving per annum = appx $9,000		
Fuel saving /donga = $9,000/40 = $225/annum		
Cost of 1mm application/ donga = $2,000		

Table 5.33: Estimated cost of fuel saving per annum for MMG bedroom air conditioning.

	CO_{2-e}/L Diesel *	**CO_{2-e}/L LNG ***
	2.67 kg	2.3 kg
25,488 L diesel	68053 kg	
85,293 L LNG		196174 kg
tonnes CO_{2-e}	68	196
Total carbon emissions = 264 tonnes CO_{2-e}		
10% saving per annum = 26.4 tonnes CO_{2-e}		
= 26.4/40** per 4-bed donga = 0.66 tonnes CO_{2-e} per annum		

Table 5.34: Estimated carbon emissions per 4-bed donga per annum at MMG Village

Note: * Liquid natural gas (LNG) is generally measured by volume or mass of gas. The energy intensity of 1 litre of LNG has been extrapolated to determine a GHG equivalent of the fuel.

** MMG has 40 4-bed dongas

This 10 percent energy saving is specific to the energy consumed by residential air conditioners and does not include common areas , such as mess, kitchen and recreation rooms areas where air conditioning is also a significant energy consumer. In both financial and carbon emission terms the 10 percent saving may look modest but if it is extrapolated across an estimated number of similar accommodation units in across Western Australia the overall saving would be significant:

- With an estimated number of mine site village dongas at 12,000 the potential carbon emission reduction could be 12,000 x 0.66 = 7,920 tonnesCO_{2-e} /annum.
- With an application cost per donga (excluding cost reduction for large numbers of application) at $2,000 the payback period would be slightly less than 10 years whilst providing a GHG emission reduction of 6.6 tonnes CO_{2-e} per donga over that period.
- If 100,000 similar dongas were treated across other industries the carbon reduction would amount to 66,000 tonnesCO_{2-e} /annum.

Whilst on site at MMG it was observed that the residents would regularly leave the air conditioners running whilst they were at work. Solutions to this issue would be to instil awareness of the significance of wasting energy, or install a mechanism whereby the air conditioner could only operate when the room is occupied. This could be, for example, a key card type mechanism or another appropriate smart mechanism. Movement sensors have been tested but were unsuccessful as they do not operate whilst the occupant is stationery during sleep even though air conditioning may still be required.

The coating can be applied at any stage, both during manufacture to any wall panel prior to assembly and as a retrofit once the building is onsite. The most significant obstacle to the coating's sustainable use is cost and the extended payback period based on energy savings. The client was advised that if the underside of the suspended floor was also coated the energy reduction would noticeably increase.

5.4 Research Q4.

What are the financial implications of the various carbon reduction methods and how does the purchase of carbon offsets complete the carbon neutral emissions account?

After the deduction of energy efficiency and behaviour change from MMG's carbon footprint the next task, on the way towards establishing MMG as a carbon neutral village, was to determine if RE's contribution to reducing energy generation from fossil fuels was substantial and sustainable. Two main questions were put:

(i) Could RE account for the balance of the carbon footprint following carbon emission reduction using energy efficiency and behaviour change programs?
(ii) Would a grid connected or standalone system produce the most sustainable result?

The following two sections consider the results of the RE system in standalone and grid connected configurations designed to maximise the reduction of MMG's operational energy. Section 5.4.1.2 looks at the design of a standalone system which has the capacity to offset the carbon emissions of all the elements of the calculated carbon footprint.

The annual energy required to operate MMG was determined as being responsible for carbon emissions of 583 tonnes $CO_{2\text{-}e}$ (see table 4.10). This fossil fuel generated operational energy created 18 – 24 percent of MMG’s annual carbon emissions (table 4.18) varying according to the projected life of the village due to the amortisation of the embodied energy.

Following an MCA a combination of low cycle generators, PV and wind were modelled as being the most appropriate with PV marginally better. As mentioned previously the modelling tool HOMER was used for the standalone situation and a new tool, REMAX, developed for the assessment of RE connected to the mine site generation plant.

In terms of the level of carbon reduction the results indicate that in both grid connected and standalone configurations the offset of carbon emissions against the village’s operational energy is small for two reasons: primarily due to the small proportion operational RE represents of the overall footprint; secondly, that there are technical limitations to the proportion of the operational energy that RE can actually offset.

5.4.1 Grid connected renewable energy carbon emission reduction

The power plant to which MMG is connected is remote to the village and located at the mine site itself. According to the installation engineers the minimum sensitivity of the generating turbines at the main plant, in response to load fluctuations, is 500 kW. As such this plant is unable to respond ‘ideally’ to the maximum load fluctuation at the village which is only 100 kW. The consequence of this, in terms of whether grid connected RE could supply MMG’s operational energy and reduce fuel consumption, is that there would be no carbon reduction or financial benefit. However, a new modelling tool, REMAX, was developed to establish if there was a situation where such an RE system could be justified

(HOMER is not designed for grid connected RE assessment and grid power supply from a mix of fuels). To this end it was assumed that the mine site generators could respond ‘ideally’ to the village loads.

Figures 4.47 and 4.48 show that RE system responding to the village loads could have financial benefits and carbon reduction capacity when connected to MMG’s generation plant. However, this advantage would only become apparent if the latter is capable of responding to the village’s small loads (<100kW). The addition of smaller output generators with sensitivity to small loads would need to be installed at the mine site generation plant. As a retrofit this would likely be uneconomic and unsustainable, but for villages with small power loads such installation could prove cost effective within six years and of environmental benefit (construction projected to 2018).

The sustainability and practicability of a RE system with generating capacity much greater than MMG’s operational energy requirement is discussed in section 5.5.4 below.

5.4.1.1 Standalone renewable energy carbon emission reduction of MMG’s operational energy emissions.

The results indicate that without energy storage a proportion of MMG’s energy use would always be generated by standby diesel generation to account for the periods when the RE systems cannot generate. The cost of storage is reducing steadily over time but the current CAPEX, to cover village loads that RE cannot support, is considered to be excessive and unsustainable as far as the financial stakeholders are concerned.

HOMER output for project commencing in 2018 indicates that for the shorter project life PV can supplement the low-cycle diesel generation but beyond a life span of 4 years wind power is the preferred option at this site. However, this is not a universal solution where the wind resource may not be as adequate as it is at MMG. In fact a multi-criteria analysis, specific to MMG, indicates a marginal bias towards PV (see Table 4.24 and Appendix 9).

It is clear from the modelling that the life span of the project is a significant factor in determining the optimum RE system to install at MMG, if only limited to reduce the emissions from the operational energy of 1.09 GWh per annum. The reduction in fossil fuel used to generate this energy, that is the penetration of the RE, is not linear as can be seen in Figures 4.50 and 4.51. Initially there is zero penetration as the power generation system HOMER models is predominantly by low-cycle diesel but beyond 3.5 years the increase in RE becomes more sustainable resulting in a higher penetration. At three years the optimum RE system has a penetration of only 20 percent rising to 83 percent at 18 years and beyond.

5.5 Research Q5.

What are the financial, technical and sustainability implications for standalone village power system power including the removal of the power supply line from the mine generating plant several kilometres away and does this distance have any material significance?

The technical implications of standalone RE to reduce operational energy emissions has been dealt with in section 5.4 and it remains for the financial cost to be discussed in order to complete the sustainability assessment.

For the RE system, and the power generation system as a whole, to be judged as sustainable the financial element must be taken into consideration. A standalone power system for a mine site village such as for MMG must, therefore, when applying cost to the equation consider the saving of removing the cost of constructing the transmission line from the mine site generation plant to the village. In a standalone generation configuration this line is no longer required and at a CAPEX of between $150,000 and $200,000 per kilometre the saving can be considerable as such villages are generally many kilometres from the mining enterprise. This is expressed in figure 4.49 for a project commencing in 2014 where it is clear that there is a substantial financial advantage if the village is situated 4 kilometres or more from the main generation plant to which, in a grid-connected configuration, it would have been connected.

The findings are, therefore, significant in that not only can a standalone RE system in a mine site village such as MMG substantially reduce the operational energy carbon emissions but can prove financially beneficial to the investing stakeholder. The modelling has been applied to a specific case study but if applied on a wider scale to larger villages, where the power loads are greater and energy consumption higher there would likely be more scope for RE with environmental and financial benefits scaled up accordingly. This reinforces the need for decisions to be made to provide mine site villages, and like remote communities, with standalone power at the planning stage rather than as a retrofit. Planning in advance will likely certainly have financial and environmental benefits.

5.6 Research Q6.

What are the financial implications of the various carbon reduction methods and how does the purchase of carbon offsets complete the carbon neutral emissions account?

The results indicate that with the modest estimated energy efficiency and behaviour change measures, together with the introduction of either grid connected or standalone RE there still remains a large proportion of the village's carbon footprint to be offset before it could be called 'carbon neutral. Table 4.25 (100% minus final column %) sets this remaining proportion at between 84.4 percent and 71 percent of the full footprint for village life spans of 5 and 20 years respectively. With collaboration of mine site village owners and operators the energy efficiency and behaviour change elements of carbon emission reduction could be substantially increased but this is generally dependent upon the cost of doing so. The size of the RE system could also be increased but again this would also be subject to a cost-benefit assessment. Several cost analyses were worked through to demonstrate their financial implications, as set out in results section 4.6.

Once the financial and practical permutations of the carbon reduction methods are worked through it becomes apparent that, if the projected life span of the development is short, the financial stakeholder is likely to only consider the purchase of accredited carbon credits. Whilst this may appear to be a rather basic approach to the issue of decarbonisation it is a practical one for mine site village developers and the like. Standalone RE is certainly a viable option but only with sufficient time for the payback period to become attractive. However, to ignore the implementation of energy efficiency and behaviour change is unacceptable in an age when carbon emission reduction is working its way to the forefront of international policy.

5.6.1 Carbon offset cost after energy efficiency, behaviour change and renewable energy are accounted for.

Section 4.6.2 and table 4.27 set out the estimated cost of energy efficiency and behaviour change at MMG, plus the cost of RE to offset against the emissions from the operational energy. These amount to between $550,000 and $220,000 per annum for village life spans of 5 and 20 years respectively, inflated largely by including the cost of installing grid connected RE.

5.6.2 Carbon offset cost after energy efficiency and behaviour change are accounted for.

Section 4.6.2 and table 4.27 give detail the estimated cost of energy efficiency, behaviour change and tree planting but without the additional cost of RE in the mix. Whilst offsetting the full carbon footprint this solution amounts to considerably less than the cost when grid connected RE is retrofitted to the generation plant but. The costs varied between $126,200 and $57,200 per annum for village life spans of 5 and 20 years respectively.

Should carbon accounting in the future becomes an issue for mining enterprises then these sums would appear to be a small additional price to pay to claim that the village and its working residents could be described as carbon neutral. Furthermore, financial credits might well be available for dealing with the carbon emissions in such a manner.

5.6.3 Cost of tree planting offset of MMG's carbon footprint

Table 4.26 includes the cost of dealing with the complete carbon footprint at MMG by purchase of carbon credits from tree planting alone and also the cost of trees to offset the remainder of the carbon footprint after the deduction of the sum of EE and BC. The results are interesting. The annual cost varies from $72,500 per annum to $54,500 per annum for village life spans of 5 and 20 years respectively and is clearly the least costly approach to decarbonisation of MMG and likely the less involved and complicated method. A price on carbon emission in Australia would reinforce this approach and provide large emitters with a simple, cost-effective, both productive and environmentally sound method of offsetting their emissions.

5.6.4 Cost of offset of MMG's carbon footprint by large fixed solar PV only

An alternative approach to dealing with the neutralization of MMG's carbon footprint is by installing a large standalone RE system without the need for EE, BC and carbon credit purchases. The modelling and subsequent calculations for a fixed array PV system to offset only MMG's carbon footprint showed that arrays of between 2.41 MW and 3.15 MW, for village life spans of 20 years and 5 years respectively, would be required. The capital cost would be from $5.31 million to $6.93 million. Such large systems would not only offset MMG's complete footprint, but would considerably reduce the amount of fossil fuelled energy generated at the mine site generation plant, as the system would be connected to both the plant and the village. The cost savings for this varied between $1.49 million and $1.54 million per annum over the two life spans thus providing short payback periods of between 3.56 and 4.5 years respectively, which would appeal to most financial analysts.

5.6.5 Comparison of costs of carbon reduction methods

Sections 5.6.1 to 5.6.4 above refer to the cost of the various methods of reducing MMG’s carbon footprint to a point of carbon neutrality. The calculations for the four selected village life spans are summarised in table 5.36:

Cost combination		**5 years**	**10 years**	**15 years**	**20 years**
		(million $)			
EE + BC + RE + tree planting *(table 4.29)*	Annual	0.55	0.35	0.27	0.22
	Lifetime	2.75	3.54	4.09	4.36
EE + BC + tree planting *(table 4.28)*	Annual	0.13	0.08	0.07	0.06
	Lifetime	0.63	0.80	0.98	1.44
Tree planting (full footprint) *(table 4.26)*	Annual	0.073	0.061	0.058	0.055
	Lifetime	0.36	0.61	0.86	1.09

Table 5.35: Cost comparison of methods to reduce MMG carbon footprint to zero.

Each method of carbon reduction referred to in table 5.35 reduces MMG’s carbon footprint to zero, but with no price put upon carbon emissions requires a significant capital expenditure. The installation of the large solar PV array (see tables 4.30 and 31), on the other hand, gives the stakeholder the opportunity to benefit from substantial financial return. The CAPEX required to realise this benefit is considerable and the returns may be limited by the period of operation of the array. However, the returns may be substantial.

If the PV stakeholder can secure a financial return from the local power utility once the mining enterprise closes then income may continue to accrue. Discussions around such a synergy would be advisable at the planning stage of a large PV installation; however, if the mine has a lengthy life span then a contract for sale of energy to the utility would not be immediately necessary but only warranted after closure.

5.7 Research Q7

Is the carbon neutral mine site village a viable proposition, or merely a desirable objective in the context of sustainable development of the built environment?

There is a general acceptance that atmospheric greenhouse gas reduction is of fundamental importance to maintaining the current way of life on this planet. As such this thesis proceeded through several lines of enquiry to establish whether a carbon neutral settlement, such as mine site village, whilst certainly a desirable objective was sustainable and had a significant role in built form GHG reduction.

Decisions for most projects are ultimately based on the availability of capital to see the project through to completion and mine site villages are no exception. The significance placed upon the social and environmental aspects of a project by the stakeholders will vary according to who is asking the question. Legislation and regulation can force the issue by insisting on the consideration of environmental matters, such as carbon emissions and energy efficiency, but in the absence of prescriptive measures short term economics will generally prevail. This is particularly obvious in the mining industry during the current era of economic instability and reducing resource markets. Consequently several calculations were made in the thesis to establish which of the solutions to reduce MMG's carbon footprint to zero were affordable and likely to receive acceptance in the board room at the time of planning or retrofit.

MMG's carbon footprint for village life spans of 5, 10, 15 and 20 years was established and the results set out in Chapter 4, along with a variety of solutions that can be applied to reduce and offset this footprint to zero. Once this point is reached MMG can be described as a carbon neutral mine site village. Whether the solutions are viable or merely desirable, in the context of sustainable development, is largely dependent upon how sustainable development is interpreted. The literature regarding this is vast and beyond the scope of this thesis. Goodfield et al., 2013 offers an approach that assists in answering the question of viability:

> "The essence of the question …… is there evidence to show that the lifetime carbon emission responsibility of a typical mine site village can be sustainably offset to a point where carbon neutrality can be legitimately claimed…. to the satisfaction of all stakeholders and avoid …..claims [that] ….. 'mislead or deceive' those relying on the information ….. and [be] relevant to this research if a future developer of similar villages makes the claim to be carbon neutral."
>
> (Goodfield *et al*., 2013)

The results when drawn together, as in table 5.35, indicate that the annual and lifetime cost of the various solutions to achieving a carbon neutral MMG are small in terms of the overall mining budget. When a revenue earning solution, such as a large fixed solar array, is considered all that needs to be determined by the financial stakeholder is whether the budget permits its inclusion.

A carbon neutral mine site village appears to be a viable proposition and certainly desirable in the context of sustainable development, but the question juxtaposes viability and desirability. It suggests that there are qualifications and limits to the measure of viability that the stakeholder may hold, particularly in terms of financial viability and these may certainly vary according to circumstance. A measure of semantics arises in determining an answer to the question but given affordable solutions mine site village constructors, owners and operators generally acknowledge the need to be energy efficient and low carbon operators.

5.8 Research Question 8

Are the metrics produced by the overall results applicable to model future carbon neutral villages of similar construction?

The generic LEVI model set out in Appendix 10 sets out a methodical approach to calculate the carbon emissions of a mine site village and built environments of a similar format. The workbook consists of seven spreadsheets representing each of the components set out in Figure 1.2 and describes how to calculate these individually. A final spreadsheet summarises a total of these emissions. A second workbook in appendix 10 utilises the generic LEVI format to specifically calculate MMG’s carbon emissions. The calculations are considered to be accurate within the limits referred to in section 5.1.

LEVI presents a basic guide and working example what to include in a calculation of the carbon footprint of a mine site village or similar build form. It incorporates all the elements contained in figure 1.2 and provides a comprehensive basis for the determination of MMG’s carbon footprint. It does not profess to be an all inclusive tool for carbon footprint assessment and reduction; however, it does provide a detailed framework which can be applied to mine site villages, retirement villages, holiday homes, and similar building development formats, where carbon emissions are under scrutiny.

The methods of reduction and offset of this footprint can be applied to any similar group of buildings or precinct and enable them to be legitimately described as carbon neutral. LEVI’s quantitative capability, whilst enabling the user to highlight the carbon intensity of individual elements of the carbon footprint, informs where the best return for effort can be made for carbon reduction and how to create a carbon neutral settlement. The boundaries of such a LCA may well differ from where they were drawn for MMG but the methodology and application remains the same.

5.9 Comparison with previous work in the field

Discussion of how the thesis compares with work done in previous research requires a brief introduction to give some context to the carbon accounting method and to the carbon reduction process followed *en route* to developing a carbon neutral MMG.

Carbon neutral development in the building industry, whilst certainly is in the minds of planners, architects, construction companies and local authorities to consider, is not at the forefront of their *modi operandi*. Even the term itself is interpreted in different ways, such as zero carbon, low carbon and carbon positive. Building regulations deal with energy efficiency (BCA, 2015) and water management to some degree mitigating carbon emissions in the process, but the general approach to construction in the Australian mining industry is compliance, primarily under the Environmental Protection Act, 1986 and associated regulatory framework in Western Australia, and the Commonwealth EPBC Act, 1999, rather than consideration of emission reduction *per se*. The approach in Europe is more proactive in carbon reduction legislation but there too, as government colours change, there is an ebb and flow towards and from dealing with the issue.

The thesis has developed a systematic method of carbon accounting for the case study mine site village which complies with international standards and can be applied to similar built forms such as retirement villages, holiday homes, group housing and the like. Seven generic sources of carbon emission have been investigated as inputs to the overall carbon footprint of the case study, MMG, namely emissions from: the embodied energy of construction; village operational energy; transport of supplies to the village; the production of food consumed; fly-in/fly-out travel to the village; waste water treatment, and; solid waste to landfill.

The carbon accounting methods for each emission source drew upon accredited sources and the overall carbon footprint of MMG calculated. With the aim of creating a carbon neutral village this was followed by a process of emission reduction and offset using reduction by the application energy efficiencies and behaviour change, followed by the introduction of renewable energy and the purchase of accredited forestry (tree planting). As one of the main pillars of sustainability is economics, the reduction and offset methods were broadly costed in order to attach a cost benefit or affordability to each method.

As discussed in Chapter 2 the term ‘carbon neutral’ in the literature has been interpreted in many different ways, as have the emissions to include within the boundaries of LCA. Even the variety of nomenclature to describe the term has many interpretations. Nevertheless, the methods of calculation and reduction of the carbon footprint of a specific group of buildings and its function, MMG mine site village, have been well defined in the thesis as has its reduction to zero.

PRECINX™ and eTool™ have been referred to in Chapter 2 that can assess the carbon intensity of a building or precinct. However there are limitations to the use of both of these tools as neither covers a sufficient proportion of the elements that comprise a precinct’s carbon footprint. These elements are detailed and illustrated in this thesis for mine site villages and similar precincts. As a result of the lack of an available tool to determine the carbon footprint of MMG a generic modelling tool described as LEVI (Low Energy Village Infrastructure) was specifically developed. This can be seen in Appendix 10 along with its application to MMG.

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Chapter 6 – Conclusions & Recommendations

6. CONCLUSIONS & RECOMMENDATIONS

The primary aims of the thesis in relation to precinct development were threefold: first, to develop a conceptual model and framework for the calculation of the carbon emissions a typical a mine site village is responsible for, its carbon footprint; second, to determine sustainable methods of reduction of this footprint to a point that the village could legitimately be described as carbon neutral; third, to develop a generic modelling tool that can be applied to similar precincts, such as retirement villages, holiday homes and remote settlements.

Mt Magnet Gold Village (MMG), situated in the Mid-West of Western Australia some 600km north of Perth, was selected as the case study upon which to base the research strategy and tool development. Eight principal questions were posited at the commencement of the research and are repeated here together with conclusions reached:

Conclusions

6.1 Research Q 1

What are the constituents of the MMG carbon footprint and how are they calculated?

The boundaries of any carbon footprint or LCA of a human settlement can be set as wide and to the level of analysis required. The elements comprising MMG's carbon footprint were extended to a point where the result could be considered as representative of a substantial proportion of the emissions the village was responsible for. The emission sources included were those from:

- The embodied energy of building infrastructure, including transport of the buildings from manufacturer to site.
- The stationery energy to operate the village (operational energy).

- The transport of supplies to the village.
- The production of food consumed in the village.
- Fly-in/fly-out transport to and from the village.
- Waste water treatment.
- Landfill waste.

Calculation of these components was covered in both the methods and results chapters.

6.2 Research Q 2

What is the overall carbon footprint of a typical mine site village?

The projected life of a mining enterprise generally predetermines the life span of the village infrastructure supporting it. This clearly has a significant effect on the overall footprint and is particularly pertinent during these current times of economic uncertainty and fluctuating resource values.

The carbon emissions for MMG were calculated under the seven selected sources for village life spans of 5, 10, 15 and 20 years and the results can be seen in table 4.18 together with their respective proportions of the annual carbon footprint. The only annual emission to change in value is the embodied energy. This change is reflected in figures 6.52 and 6.53 below, highlighting how the embodied energy reduces as a proportion over increasing time spans and how this reduction is reflected in the proportion of the full footprint each emission sources represents. As the annual embodied energy emissions conceptually reduce over time so the other elements form a larger proportion of the total. It can also be seen in the results table that for a life span of ten years or more for MMG three areas of village activity account for approximately 75% of total emissions: fly-in and fly-out travel to and from the village according to the set roster are the most significant; emissions relating to the production of food consumed; and the operational energy consumed to run the village.

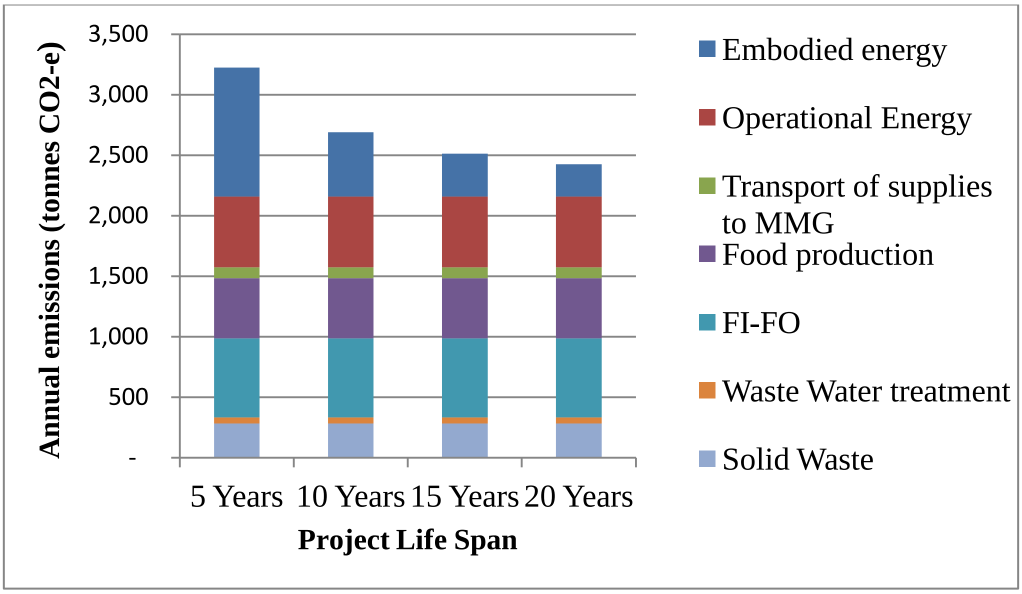

Figure 6.52: MMG annual emissions compared over life spans of 5, 10, 15, & 20 years

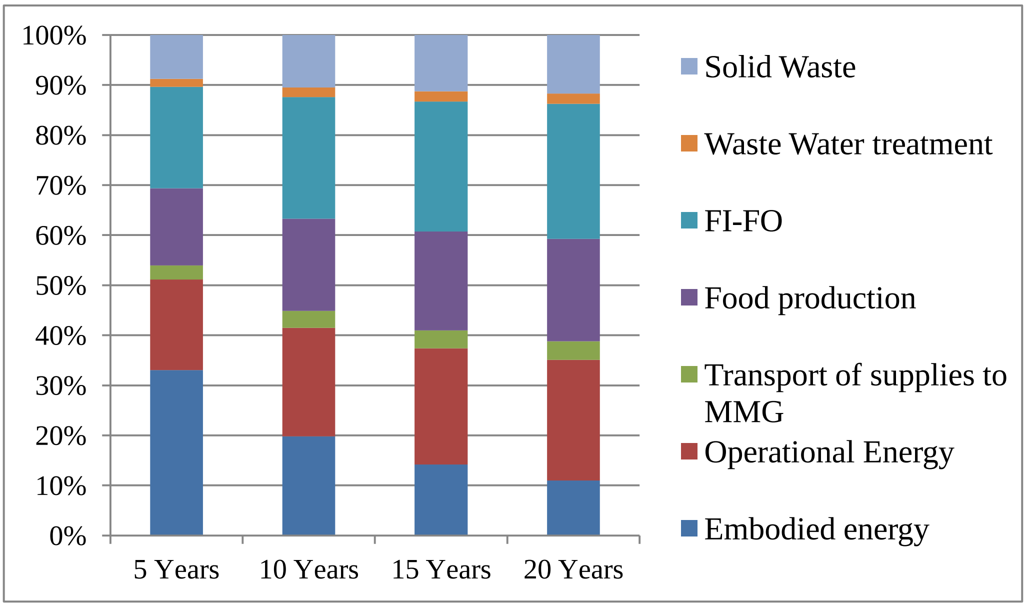

Figure 6.53: MMG annual emissions proportion of full carbon footprint over life spans of 5,10, 15, & 20 years

Table 6.36 below summarises the total annual carbon emissions of MMG for each life span and includes an apportionment to each village resident. The size of the individual footprint is noteworthy when it is compared to the average footprint reported on Australia's carbon emissions – from approximately 14 tonnes $CO_{2\text{-}e}$ per person per annum (DPI, 2008) to 28 tonnes $CO_{2\text{-}e}$ per person per annum quoted in the Garnaut (2008), the disparity being due to the where boundaries of the LCA have been drawn. The data forming the graph figure 4.37 above represents the data in table 6.36 and emphasises the reduction in the individual footprint over increasing village life spans. The main conclusion drawn from this is that the carbon footprint each worker living at the MMG village can be twice that from living and working in the metropolitan area.

Lifespan (years)	**Total MMG Emissions per annum over lifespan (Tonnes CO_{2-e})**	**Total Emissions per MMG worker per annum (Tonnes CO_{2-e})**
20	2424	15
15	2513	16
10	2690	17
5	3223	20

Table 6.36: Comparison of total carbon emissions for MMG apportioned per MMG resident.

Figure 6.53 shows that for an anticipated life span of 5 years the emissions attributable to the embodied energy of the buildings and infrastructure is the largest proportion of the total carbon footprint of MMG Village. This reduces significantly for a life span of 10 years to be approximately equal to the emissions from the operational energy and food production leaving the emissions from fly-in/fly-out air travel the largest.

6.3 Research Q 3

What is the extent of carbon reduction when energy efficiency, behaviour change measures and renewable energy are applied and how much do they contribute to reducing MMG's carbon footprint en route to carbon neutrality?

Energy efficiency (EE) and behaviour change (BC) have the capacity to reduce MMG's carbon emissions according to the sources included in the calculation. As the choice of measures and systems under both headings are unlimited a broad estimate had to be made and the carbon emissions calculated accordingly. A reduction of 281 tonnes CO_{2-e} per annum was calculated – see table 4.19.

The degree to which EE & BC contributes to carbon emission reduction at MMG varies according to the projected village life span. Table 4.20 sets these out indicating a minimum of approximately a 9 percent reduction per annum for life span 5 years and 12 percent for 20 years. Much more can be achieved in this area of carbon reduction but sustainable solutions must include a reasoned element of affordability for the stakeholders. The reductions herein have accordingly taken this into account.

6.3.1 Ceramic coat contribution to energy efficiency

Apart from other practical elements performed during this research, such as the installation of a comprehensive monitoring system at MMG, an experiment was carried out to determine the reduction in energy consumed by active air conditioning following the coating of a typical transportable accommodation module (donga) with a 1mm thick ceramic coating applied to the exterior walls and roof.

The results of the experiment presented in section 4.3.1.1.1 are discussed in section 5.3.3.1. Significant conclusions were:

1. That the air conditioner in the coated donga consumed approximately 10 percent less energy than the uncoated building.
2. That when applied to all MMG accommodation units a 10% fuel saving would reduce the village's carbon footprint by 26.4 tonnes CO_{2-e} per annum and reduce annual expenditure on diesel and gas fuelled energy generation by approximately $9,000.
3. That the overall energy and cost savings would increase significantly if the common area buildings, kitchen, dining room, administration, communications, and gymnasium were also coated.

4. The cost of the application for all 40 dongas at around $80k would set a simple payback at around 10 years, reducing as the cost of diesel and gas increases..
5. Applying the coating to say 12,000 dongas across the mining industry would reduce emissions by approximately 8,000 tonnes $CO_{2\text{-}e}$ /annum.
6. If applied to say 100,000 similar buildings across a variety of industries in the emissions reduction would be 66,000 tonnes$CO_{2\text{-}e}$ /annum.

6.4 Research Q 4

What is the appropriate renewable energy technology choice for MMG and what configuration will offset the stationary energy required for operation on a daily basis? How does renewable energy impact the overall carbon account in both standalone and mine site grid connected configurations?

MMG's carbon footprint has been established for the four selected village life spans and a conservative estimate of EE and BC made. Table 4.20 shows the remaining annual emissions to be offset or reduced in order to reach a point of carbon neutrality for the village. The research question asks:

(i) What is the appropriate RE technology choice at MMG to maximise the reduction of emissions from the stationery energy generation?
(ii) What RE configuration is appropriate at MMG?
(iii) What is the impact of both standalone and grid connected RE at MMG?

Renewable energy at MMG

RE at MMG can be either grid connected to the mine site generation plant or as a standalone system.

6.4.1 Standalone RE at MMG

The research indicated that standalone technology choice was conditional primarily upon the projected lifespan of the village and the distance of the village from the mine site generation plant.

Village life span condition

The modelling tool, HOMER, indicated that the penetration of RE increased the greater the projected life of the village and according to when the project was due to commence. The HOMER output for a project commencing in 2018 can be seen in table 4.21 where for a project life of 5 years the RE penetration into the operational energy element of power generation would be 70 percent. The modelled configuration was a mix of 300 kW of wind turbines and low-cycle low-load diesel generators made up of 50, 100 and 150kW outputs.

The modelling showed that as the projected life of the village increased so did the penetration of the RE, but only to a maximum of 83 percent, the remainder being generated by the low-cycle diesel generators referred to earlier. However, the carbon reduction potential of the RE still remains low because it can only represent the proportion of the emissions from the village's 1.09GWh/annum operational energy. Larger RE systems, beyond the generating capacity to set against MMG's operational energy consumption, are referred to in section 4.6.4.

Distance from the mine site generation plant condition

In order to avoid airborne particulate and noise pollution emanating from a mining enterprise, without exception mine site villages are situated an appropriate distance from the mine itself. This may well be the case for similar remote precinct development. Standalone RE generation for the village negates the requirement to construct the necessary 3-phase transmission lines from mine site generation plant to the village. Removing the need for this connection presents a substantial saving to the financially responsible stakeholder. The results, section 4.5 indicate that, in the case study example, the financial benefit is dependent not only upon a minimum distance from the mine site generation plant and village but also upon the life of the village. Figure 4.49 indicates that financial advantage occurs with a projected village life span of 7 years or more with a minimum distance between mine site generation and village of 4 kilometres. The greater this distance and the longer the anticipated life span of the village is, the more financially sustainable the installation of a standalone RE system becomes.

6.4.2 Grid connected RE at MMG

The development of REMAX, a software tool capable of modelling grid connected RE systems and systems which have multiple fuel sources as at MMG (LNG and diesel), provided several conclusions:

1. MMG's mine site power generators were unresponsive to the small load fluctuations at by the village. The former did not have a sensitivity to loads < 500kW whereas the village loads variance was rarely >100kW.
2. As the current configuration of MMG's generation plant stands at present there would be no environmental or financial benefit to retrofit the village with grid connected RE.
3. If MMG's generation plant was modified to include turbines capable of responding to the village's small loads, that is to respond 'ideally' to the applied loading, then the retrofit of a grid connected RE system could be sustainable. However, analysis indicates, as shown in figure 4.47 that the main generation plant would need to be fully responsive to produce a sustainable result, using 2014 figures, for a village life span of nine years or longer. For a project commencing in 2018 a sustainable outcome is projected to commence if the village life span be six years or longer – see figure 4.48.

6.5 Research Q 5

What are the financial, technical and sustainability implications for standalone village power system power including the removal of the power supply line from the mine generating plant several kilometres away and does this distance have any material significance?

The technical implications of standalone RE to reduce operational energy emissions has been dealt with in the section 6.4.1.

Removing the need to construct the 3-phase 22-kV transmission line connection between generation plant and village would produce a CAPEX saving in the region of $150k $200 per kilometre (WorleyParsons, 2011). NPC analysis indicates that a cost benefit begins to accrue with a project life of seven years or more – see figure 4.49. Table 6.37 below compares the CAPEX advantage and disadvantage for three lengths of line removal if the projected life of the village is 18 years, for a project commencing in 2014:

Grid connected transmission line	CAPEX (appx.)
2km	Minus $50,000
4km	Plus $450,000
6km	Plus $1,000,000

Table 6.37: CAPEX savings of removing various lengths of transmission line connection

These savings increase with later village commencement dates due to increased cost in fossil fuelled grid connected generation and reduced cost of RE.

6.6 Research Q 6

What are the financial implications of the various carbon reduction methods and how does the purchase of carbon offsets complete the carbon neutral emissions account?

Some of the costs of methods to reduce MMG’s carbon footprint have already been referred to in this chapter. Reduction of the footprint to zero permits the description of MMG as ‘carbon neutral,’ whilst reduction and offset of emissions beyond this point enables the village to be described as ‘carbon positive.’ Table 4.32 sets out the approximate cost of various reduction and offset measures over the four village life spans referred to in the results and discussion chapters, for a project commencing in 2018 with costs rounded to the nearest $1,000.

Referring to the installation of a large PV array, once the payback period has been reached the system will continue to generate and be a substitute for fossil fuelled generation at the mine site plant. The array will, therefore, continue from this point to earn for the stakeholder by reducing the fuel expenditure throughout the remainder of the lifespan. Table 4.30 shows that the earning capacity of the array would be in the order of M$2.55 for a village life span of 20 years, at an initial cost of M$5.31 producing a cost benefit of M$2.08. Whilst an NPC account of costs may produce a slightly less optimistic result, it is clear that the investment of $5.3 million begins to earn substantial sums for the stakeholder providing the array is in operation for 20 years. The longer it operates the greater the earnings.

Should the mining operations cease prematurely the financial advantage of a large scale PV array, or alternative source of RE, may be lost. In such circumstance it would be advantageous for the stakeholder to have come to a financial arrangement with the local power utility to connect the now redundant RE supply to the power company’s grid. In the case of MMG this would be Horizon Power who supply Mt Magnet town with LNG powered energy.

6.7 Research Q 7

Is the carbon neutral mine site village a viable proposition, or merely a desirable objective in the context of sustainable development of the built environment?

In addition to the cost comparison of the various carbon reduction methods, set out in table 4.32 above, a financial summary of the solutions for a carbon neutral MMG and leaving aside the construction of a large PV array, it becomes apparent that:

- For short village life spans (up to 15 years) the most affordable method is merely to purchase accredited carbon offsets such as planting trees.
- Standalone RE, when sized to offset only the operational energy consumed by the village, does not present an economic solution.

If the large PV array installation is considered, sized specifically to offset MMG's full carbon footprint, though it requires a substantial capital outlay, it is capable with a village life of 5 years or more of earning the stakeholder substantial returns.

The answer to the research question is that carbon neutral mine site villages, and similar precincts, are definitely achievable in a sustainable manner but subject to a number of conditions highlighted in the thesis. However, the analysis of clearly shows that without a price being applied to carbon emissions, over an agreed cap, that the most cost effective way to render a mine site village carbon neutral is to purchase carbon offset ACCUs from accredited forestry or alternative clean development mechanisms (CDMs). The Sankey diagrams in figures 6.54 and 6.55 show that offset purchases (orange) provide the main solution with some results manifesting a visible contrast between the two contrasting life spans. The carbon emissions for village life spans of 5 and 20 years appear in an alternative histogram format form in figures 6.52 and 6.53 above, wherein the comparison can again be made.

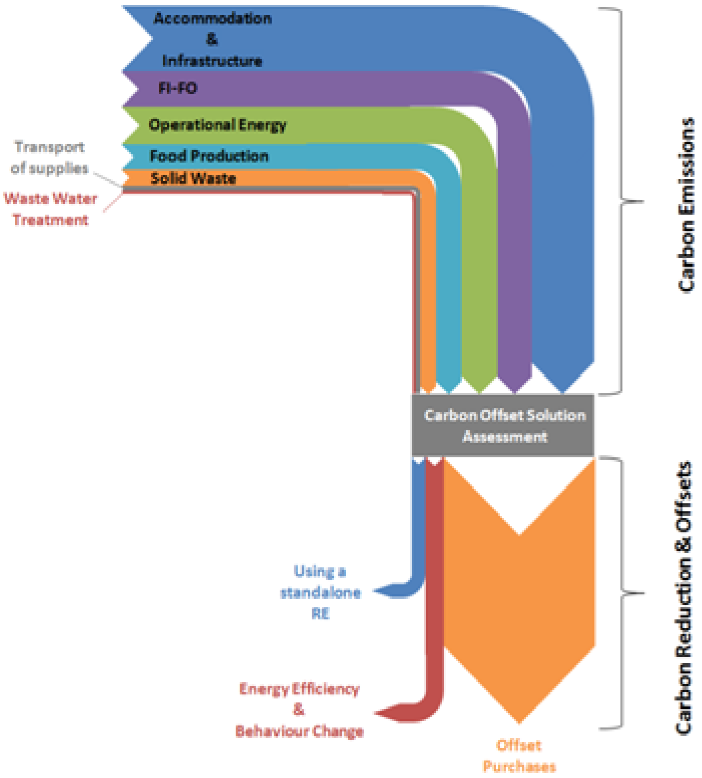

Figure 6.54: Carbon emission, reduction and offsets compared for MMG with 5 year life span

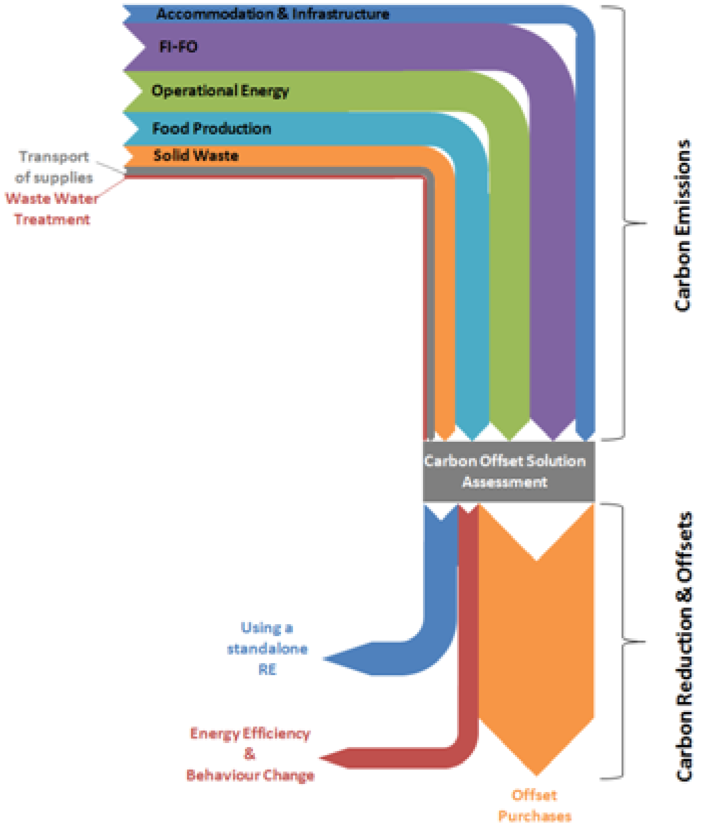

Figure 6.55: Carbon emission, reduction and offsets compared for MMG with 20 year life span

6.8 Research Q 8

Are the metrics produced by the overall results applicable to model future carbon neutral villages of similar construction?

The generic modelling tool, LEVI, was developed in an Excel workbook and discussed in section 5.7. The generic tool can be found in Appendix 10 and is populated by data from MMG, also in Appendix 10. Each worksheet represents an element of carbon emission calculation with the final sheet producing a summary and total carbon footprint. LEVI is discussed in greater detail in section 5.8 but it is clear that it can be applied not just to mine site villages but to other precincts where a carbon emissions account is required, such as caravan parks, retirement villages, holiday homes and remote settlements.

6.9 Summary of Conclusions

- A conceptual model framework to establish a precincts' carbon footprint (figure 3.14) provides a basis for the carbon emission calculation.
- The overall carbon footprint of MMG mine site village is set out in table 4.18, based on the constituents of the footprint (Figure 1.2) and the conceptual model (figure 3.14).
- LEVI informs that three elements of the carbon footprint stand out for further investigation: the embodied energy of MMG; fly-in/fly-out ait travel to MMG; and food consumed in the village. Together these total 62 and 58 percent for life spans of 5 and 20 years respectively.
- That the life span of the buildings and infrastructure has a significant effect on the overall result.
- A stakeholder's commitment to sustainable development governs the degree to which energy efficiency and behaviour change programs can reduce carbon emissions, and the results can vary significantly.
- The energy efficiency of MMG's buildings and infrastructure can be significantly increased by: more energy efficient materials of construction and design; smart control systems; and grey water reuse for landscaping to reduce the energy required to treat waste water.

- The capital outlay and cost of energy efficiency measures can prohibit implementation for many stakeholders.
- A 0.5mm ceramic thermal coat can reduce air conditioning energy consumption by 10 percent.
- Utilising locally grown food would produce a significant reduction in carbon emissions.
- A change of the fly-in/fly-out roster from 8 days on 6 off to 14 and 7 would reduce these transport emissions by 34 percent.
- Substitution of MMG's operational energy consumption (1.09GWh per annum) with a grid-connected RE system is technically demanding and not cost effective in the short term (< 6 years).
- A standalone RE system at MMG is financially beneficial to the stakeholder (see Figure 4.52) and produces a substantial carbon emission reduction (see Figures 4.53 and 4.54). A standalone system negates the need for power line construction (> 4 km) from the mine site generation plant to the village and saves substantial installation costs.
- For MMG with small peak loads of <500kW a hybrid power generation system consisting of low cycle diesel generator(s), a PV array and/or wind turbine RE, provides the optimum return on investment and carbon reduction.
- A substantial investment of a large fixed solar array (2.5 MW appx.) will produce a financial benefit and significantly reduce MMG's carbon footprint if it operates for longer than 5 years. Furthermore, a price on carbon would substantially increase the financial return.
- The purchase of tree planting carbon credits from an accredited agency is the most cost effective method to offset MMG's carbon footprint. However, to exhibit sound corporate responsibility alternative methods of carbon reduction, such as energy efficiency, behaviour change, and the introduction of renewable energy are essential.
- LEVI is a practical and useful tool to use in the calculation of a precinct's carbon footprint.

Recommendations

6.10 Recommendations for further research

The carbon reductive effects of energy efficiency and behaviour change programs have been estimated in the thesis. Further research could be done in these areas to substantially reduce MMG’s carbon footprint. Doing so, however, begs the question whether the measures taken would be cost prohibitive and render such increases unsustainable.

It is recommended that further research be done to determine the sustainability and cost benefit to the various stakeholders of measures that could include:

- Passive solar design principles for overall village design.
- New construction materials and building design for better thermal performance.
- Smart systems for better energy efficiency.
- Grey water reuse for landscaping to reduce energy required for desalination.
- Landscaping to reduce the heat island effect and improve social amenity.
- Ground source heating and cooling for common areas as a substitute for power consuming air conditioners.

6.11 Recommendations to implement outcomes of the research

The following recommendations come directly from the results of the research:

1. Mine site villages and the like can be made carbon neutral. The most sustainable results can be achieved by planning changes during the formation of the design brief and not when the design is set. The recommendation is that developers include environmental and renewable energy engineers at the inception of development plans at an earlier stage than anecdotal evidence indicates they do.
2. Some of the recommended measures require that education programs be run for users to maximise benefit of the new system and minimise resistance to usage.

3. It is recommended that the building envelope of the lightweight transportable module, for residential accommodation and commercial use alike, be redesigned with more energy efficient materials. Furthermore, that field tests be done.
4. That software development of LEVI be done based on the model in Appendix 10. As society demands low carbon construction and operation of new precinct development a user friendly version of LEVI could provide a useful tool to assess and reduce carbon emissions and move towards an accredited carbon neutral account. This will certainly be of benefit if and when carbon emissions come at a cost.
5. That investigation be made, at the design stage recommended in point 4, with power utilities to establish the policy and regulation of integrating large RE system(s) with township power supply when the mine and village are closed and the array left operational. This could improve the community ties with the local council and population.

REFERENCES

Aboudi, M., & Talevski, A. (2010). *Environmental Sustainability and Improved Quality of Life Through Service Convergence Technologies.* 24th IEEE International Conference on Advanced Information Networking and Applications.

ABS (2007). Australian Bureau of Statistics. Household trends. Accessed online at http://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/8DD7826E7F7235D8CA25732C0020820B?opendocument#TRENDS%20IN%20HOUSEHOLD%20COMPOSITION

ABS (2012). Australian Bureau of Statistics. Energy Account, Australia, 2012-13. Accessed online at http://www.abs.gov.au/ausstats/abs@.nsf/mf/4604.0

ACCC (2008). Australian Competition & Consumer Commission. *Carbon claims and the Trade Practices Act.* Accessed online at http://www.greenwashreport.org/downloads/ACCC_Carbon.pdf

ACCC, BHP Billiton Group (2010). Letter to task group on energy efficiency, 17th June 2010, sourced online at http://www.climatechange.gov.au/government/submissions/pm-task-group/~/media/submissions/pmtaskforce/papers/197-bhp-billiton.ashx, accessed 12/9/11.

Anda, M., Goodfield, D., Harries, D., Ho, G., & Newman, P. (2007). Report for Rio Tinto Iron Ore Ltd: Sustainable Minesite Camp Accommodation. Murdoch University, Australia.

Anda, M., Dallas, S., Everard, C., Harries, D., Sharma, H., Goodfield, D., Hodgson ,N., & Humphries, S. (2008). Fortescue Metals Group: FMG Sustainable Village Design, Report, Murdoch University, Australia.

ASBEC (2011). Australian Sustainable Building Council. *Defining Zero Emission Buildings: Review & Recommendations*. Accessed online at http://www.asbec.asn.au/files/ASBEC_Zero_Carbon_Definitions_Final_Report_Release_Version_15112011_0.pdf

Australian Mining News (2015). *Solar project to commence at Degrussa.* An online editorial at http://www.australianmining.com.au/news/solar-project-to-commence-at-degrussa, accessed 20/7/2015

Batten K.(2009). Interview with Prof. Chem Nayer in Mining News 2July, 2009. Accesses online at http://www.miningnews.net/storyView.asp?storyID=1030686&feature=Cost+Control&sectionsource=f74300&aspdsc=yes

BHP (2013). BHP Billiton *Resourcing the Future Sustainability Report*. Sourced online at http://www.bhpbilliton.com/society/reports/2013-bhp-billiton-sustainability-report

BP (2012). *British Petroleum Statistical Review of World Energy 2012*. Accessed online at http://www.bp.com/content/dam/bp/pdf/Statistical-Review-2012/statistical_review_of_world_energy_2012.pdf

Brown, L. (2009). *Plan B 4.0: Mobilizing to Save Civilization.* Earth Policy Institute, New York, US.

Burke, J. (2011). *Australia's first 100% renewable energy-powered mine.* Report online in Australia Mining News http://www.miningaustralia.com.au/news/australia-s-first-100-renewable-energy- powered--1-- .

Carbon Neutral (2011). A not-for profit Australian company that investigates carbon neutral claims and assists corporations and government bodies in reducing emissions, sourced online at http://www.carbonneutral.com.au/organisations/being-carbon-neutral.html

Carbontracker Initiative (2013). *Unburnable Carbon: Are the world's financial markets carrying a carbon bubble?* Accessed online at http://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf

CEFC (2015). Clean Energy Finance Corporation and Sandfire Resources. Australia's largest solar and battery storage project. Accessed online at http://www.cleanenergyfinancecorp.com.au/media/releases-and-announcements/files/cefc-finances-major-solar-storage-project-at-remote-mine.aspx

CERES (2008). *Food Miles in Australia* in Australian Greenhouse Office (AGO) Factors and Methods Workbook, Department of Environment and Heritage (2006), accessed online at http://www.theage.com.au/ed_docs/food_miles.pdf

Chong, W.K. (2008). Technical Metabolism and Building Designs, *Proceedings of the International Conference on Waste Engineering and Management*. Hong Kong, pp. c11– c17.

Clean Energy Regulator (2015). *Emissions Reduction Fund.* Sourced online at http://www.cleanenergyregulator.gov.au/About/About-the-Clean-Energy-Regulator

Climate Institute, The (2013). Vivid Economics, *G20 low carbon competitiveness index: 2013 update*, report prepared for The Climate Institute, February 2013. Accessed online at http://www.climateinstitute.org.au/verve/_resources/TCI_GlobalClimateLeadershipReview_LCCIFactsheet_March2013.pdf at p.12

DCC&EE (2010). Department of Climate Change & Energy Efficiency. *National Carbon Offset Standard* (NCOS) sourced online at http://www.environment.gov.au/climate-change/carbon-neutral/ncos

DCC (2011).Department of Climate Change and Energy Efficiency. G*reenhouse Friendly*. Accessed online at http://www.climatechange.gov.au/greenhousefriendly/

De Vries, B (2012). *Sustainability Science.* Cambridge University Press, UK. at p.448

Department of the Environment (2014). *Carbon Farming Initiative*. Accessed online at http://www.environment.gov.au/climate-change/emissions-reduction-fund/carbon-farming-initiative-project-transition

DoE (2013a). Department of Environment. Emissions Reduction Fund and Australian Carbon Credit Units under Kyoto. Accessed online at http://www.environment.gov.au/climate-change/emissions-reduction-fund/cfi/kyoto-and-non-kyoto-activities

DoE (2013b). Department of Environment, *National Carbon Offset Standard* (NCOS). Accessessed online at http://www.environment.gov.au/climate-change/carbon-neutral/ncos

DoE (2013c). Department of Environment, *Going carbon neutral*. Accessed online at http://www.environment.gov.au/climate-change/carbon-neutral

DIICCSRT (2013). Department of Industry, Innovation, Climate Change, Science, Research, and Tertiary Eductaion *National Greenhouse and Energy Reporting System Measurement: Technical Guidelines for the estimation of greenhouse gas emissions by facilities in Australia* (NGERS). Accessed online at http://www.environment.gov.au/system/files/resources/a1f1d8e6-6994-47ef-a6fa-f315084b33f2/files/nger-measurement-technical-guidelines-july-2013.pdf

DRET (2011). *A Guide to Leading Practice Sustainable Development in Mining.* Sourced online at http://www.industry.gov.au/resource/Documents/LPSDP/guideLPSD.pdf

Eisfeld, A., Karduck, A.P. *Service Infrastructure Evolution: Facing Challenges with Semantic Web Technologies.* IEEE International Conference on Digital Ecosystems and Technologies, (DEST 2012), June 18-20 2012, Campione, Italy.

eTool (2015). Analysis software for sustainable design, sourced online at http://app.etool.net.au/

Flannery, T (2005). *The Weather Makers: The History and Future Impact of Climate Change.* Text Publishing, Melbourne, Australia.

Garnaut, R. (2008). *The Garnaut Climate Change Review- Final Report*. Cambridge University Press, Melbourne. Accessed online at http://www.garnautreview.org.au/index.htm

Glencore (2010). *Sustainable Business Growth: Integrating Sustainability*. Half year report accessed online at http://www.glencore.com/sustainability/

Gore, A. (2006). *An Inconvenient Truth: The planetary emergency of global warming and what we can do about it*. Rodale Press, Pennsylvania, US.

Gore, A. (2009). *Our Choice: A Plan to Solve the Climate Crisis*. Rodale Press, Pennsylvania, US.

Goodfield D, Anda M, Ho G. (2011). *Carbon Neutral Mine Site Accommodation Village: Developing the Model*, conference proceedings MODSIM, Perth, WA 2011. Peer reviewed conference paper.

Goodfield, D., Anda, M. and Ho, G. (2014) *Carbon neutral mine site villages: Myth or reality?* Renewable Energy, 66 . pp. 62-68.

Gössling, S., & Schumacher K.P., (2010) *Implementing carbon neutral destination policies*: *issues from the Seychelles*, Journal of Sustainable Tourism, 18:3, 377-391.

Government of South Australia (2009). Environmental Protection Authority, *Worksheet 3: Calculating your greenhouse gas emissions from flights.* Taken from World Resources

Institute, Greenhouse Gas Protocol, 2007, accessed online at https://www.lga.sa.gov.au/webdata/resources/files/Council_Inventory_Worksheet_v1_20110831.pdf

Government of Victoria (2012). *Home Technical Manual.* Accessed online at http://www.yourhome.gov.au/

Green, M. (2013). *Bursting the Carbon Bubble*. News report, Sydney Morning Herald, Feb. 15. Accessed online at http://www.smh.com.au/business/carbon-economy/bursting-the-carbon-bubble-20130214-2efob.html

Hamilton, C., J. Kellett, and X. Yuan (2007). *Carbon profiling: an analysis of methods for establishing the local emissions baseline.* School of Natural Built Environments, University of South Australia & Centre for Design, RMIT, Melbourne.

Hardisty, P.E. (2010). *Environmental and Economic Sustainability*, CRC Press, Florida, USA.

Hart S.L. (1997). *Beyond Greening: Strategies for a Sustainable World.* Harvard Business Review for 1997. Accessed online at http://www.stuartlhart.com/sites/stuartlhart.com/files/Beyond%20Greening%20PDF_0.pdf

Horne, R., T. Grant, and K.Verghesse (2009). *Life Cycle Assessment: Principles, Practice and Prospects*, CSIRO Publishing, Collingwood, Victoria.

HOMER (2010). HOMER v.2.81®, Homer Energy, Optimising Clean Power Everywhere, Energy modelling software for hybrid renewable energy systems, Boulder, USA, sourced online at http://homerenergy.com, accessed 10/8/11.

IKS (2014). Monitoring, control and automation systems. Accessed online at http://www.iks-automation.com.au/imca/controller/imca_controller.php

International Organisation for Standardisation (2006). ISO 14040:2006 & 14044:2006. *Environmental management, Life cycle assessment, principles and framework Requirements & guidelines.*

International Organisation for Standardisation (2013). ISO/TS 14067:2013. *Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication.* Sourced online at http://www.iso.org/iso/catalogue_detail?csnumber=59521

IPCC (1990). Intergovernmental Panel on Climate Change. *Scientific Assessment*. Accessed online at https://www.ipcc.ch/ipccreports/far/wg_I/ipcc_far_wg_I_full_report.pdf

IPCC (1992) Intergovernmental Panel on Climate Change. *Supplement to 1990 Report* sourced online at https://www.ipcc.ch/ipccreports/1992%20IPCC%20Supplement/IPCC_1990_and_1992_Assessments/English/ipcc_90_92_assessments_far_1992_ipcc_suppl.pdf

IPCC (2013). Intergovernmental Panel on Climate Change. Climate *Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report at

Cambridge University Press, UK. Accessed online at http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

Karduck, A.,, Proskurin, S., McMeekin., D (2012). *Smart Camp:Building Scalable and Highly Available IT-Infrastructures.* 6th IEEE International Conference on Digital Ecosystems and Technologies (IEEE-DEST 2012), Jun 18-20 2012. Campione, Italy

Kinesis (2015). CCAP Precinct software known as PRECINX, accessed online at http://www.kinesis.org/ccap-precinct/

Kohn M., Oslislo, L., Chang, E., Karduck, A., & Talevski, A. (2010). *Smart Camp A Sustainable Digital Ecosystems Environment.* IEEE international conference on digital ecosystems and technologies (DEST 2010), Apr 12 2010, pp. 407-413. Dubai, UAE.

Lee, K., Murray, D., Goodfield, D., & Anda, A. (2012). *Experiences and Issues for Environmental Engineering Sensor Network Deployments.* IEEE-DEST Conference – 2012 Campione, Italy, 18-20 June.

Lisle, J & Sim, R. (2010). *Eco-village Sustainability investigation – Jack Hills Expansion Project* for Cardno (WA) Pty Ltd. Accessed online at http://www.epa.wa.gov.au/EIA/EPAReports/Documents/1413/6.%20Cardno%20Eco%20Village%20,%202010.pdf

Marszal A.J. *et al* (2011). *Zero Energy Building – A review of definitions and calculation methodologies.* Energy and Buildings 43 (2011) 971–979.

McKenzie-Mohr, D., and W. Smith (1999). *Fostering Sustainable Behaviour: An Introduction to Social Marketing.* New Society Publishers, Gabriola Island, B.C., Canada, pp.19–45.

McKibben, J. (2013). Report in The Fifth Estate with reference to Robert Tromop of the International Energy Agency, 5March, 2013. Accessed online at http://www.thefifthestate.com.au/spinifex/new-tools-for-tinkerers-the-changing-role-of-buildings-managers/45191

Murray J., & Dey C. (2007). *Carbon neutral – sense and sensibility*. Centre for Integrated Sustainability Analysis, University of Sydney, NSW, accessed online at http://www.isa.org.usyd.edu.au/publications/CarbonNeutral.pdf , 7/9/11.

National Geographic (2012). The Great Energy Challenge. Europe’s First Carbon Neutral Neighbourhood, July 2012, accessed online at http://energyblog.nationalgeographic.com/2012/07/03/europes-first-carbon-neutral-neighborhood-western-harbour/

NGA (2014). Commonwealth of Australia, Dept. of Environment, *National Greenhouse Accounts Factors:* Australian National Greenhouse Accounts, sourced online at http://www.environment.gov.au/system/files/resources/b24f8db4-e55a-4deb-a0b3-32cf763a5dab/files/national-greenhouse-accounts-factors-2014.pdf

Origin Energy (2014). Electricity generation across Australia in Australia Energy Regulator State of the Market 2014. Accessed online at https://www.aer.gov.au/sites/default/files/State%20of%20the%20energy%20market%202014%20-%20Complete%20report%20%28A4%29_0.pdf

Oslislo, L., Talevski, A., Karduck, A.P., (2011): *Smart Camp: Benefits of Media and Smart Service Convergence*. 25th IEEE International Conference on Advanced Information Networking and Applications, March 22-25 2011, Singapore.

PAS (2011). Publicly Available Specification 2050:2011. *Specifi cation for the assessment of the life cycle greenhouse gas emissions of goods and services.* Sourced online at http://shop.bsigroup.com/upload/Shop/Download/PAS/PAS2050.pdf

Ploumis, M. (2011). *Mine site village carbon emissions and engineering offset solutions:* An industry internship for the degree of Bachelor of Environmental Engineering, Murdoch University, unit ENG450 available online at http://researchrepository.murdoch.edu.au/6858/

RETScreen (2011). RETScreen v.4™ Clean energy project analysis software, sourced online at http://www.retscreen.net/ang/home.php

RTIO (2011). Rio Tinto Iron Ore. Company website on climate change sourced at http://www.riotinto.com/ourapproach/17214_climate_change.asp , accessed 12/9/11.

RTIO (2011). Annual Report accessed online at http://www.riotinto.com/documents/Investors/Rio_Tinto_2011_Annual_report.pdf

Sayigh A. *ed* (2014). *Sustainability, Energy & Architecture: Case Studies in Realizing Green Buildings.* Academic Press, UK.

SMEC (2008) *DPI Living Smart Report*. Department for Planning and Infrastructure, for Government of Western Australia. http://www.dpi.wa.gov.au/livingsmart

SKM (2008). *Improving the sustainability of mine camps*, Sinclair Knight Merz magazine, sourced online athttp://www.skmconsulting.com/Knowledge-and-Insights/Achieve-Articles/2009/Improving-Sustainability-of-Mine-Camps.aspx, accessed 2/12/09

Stern, N. (2006). *The Economics of Climate Change: The Stern Review*. Cambridge University Press, UK. Accessed online at http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf

Sturgis, S. & Roberts, G. (2010). *Redefining Zero*: Carbon profiling as a solution to whole life carbon emission measurement in buildings. 2010, RICS, London.

UN-Habitat (2011). *Global report on human settlementS 2011: Sustainable Cities and Climate Change.* Accessed online at http://unhabitat.org/books/cities-and-climate-change-global-report-on-human-settlements-2011/

UNEP (2009). United Nations Environment Program. *Draft International Standard for Determining Greenhouse Gas Emissions for Cities.* Accessed online at http://www.unep.org/urban_environment/PDFs/InternationalStd-GHG.pdf , 25/3/14

UNEP (2010). United Nations Environment Program, 5th World Urban Forum
Rio de Janeiro, Brazil. *Draft International Standard for Determining Greenhouse Gas Emissions for Cities.* Accessed online at http://www.unep.org/urban_environment/PDFs/InternationalStd-GHG.pdf, 6/11/12

UNEP-SBCI (2009). United Nations Environment Program: Sustainable Buildings & Climate Initiative. *Buildings and Climate Change*. Sourced online at http://www.unep.org/sbci/pdfs/sbci-bccsummary.pdf

UNFCC (2012). United Nations Framework Convention on Climate Change: Kyoto Protocol. Accessed online at https://unfccc.int/kyoto_protocol/items/2830.php

Victoria State Government (2015). *Sustainability Victoria* accessed online at http://www.sustainability.vic.gov.au/

Wiedmann, T.,& Minx J. (2008). *A Definition of Carbon Footprint*, in C. C. Pertsova (ed.) *Ecological EconomicsResearch Trends*, pp. 1–11, Nova Science Publishers, Hauppauge, NY, USA, sourced online at http://www.censa.org.uk/docs/ISA-UK_Report_07-01_carbon_footprint.pdf, 7/9/11.

WRI (2010). World Resources Institute & World Business Council for Sustainable Development. *The Greenhouse Gas Protocol*: A Corporate Accounting & Reporting Standard- revised edition. Accessed online at http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

WRI (2015). World Resources Institute. Online web post: Australia Offers Lackluster 2030 Climate Target, sourced at http://www.wri.org/blog/2015/08/australia-offers-lackluster-2030-climate-target?utm_campaign=wridigest&utm_source=wridigest-2015-08-18&utm_medium=email&utm_content=learnmore

Xtrata (2011). Climate change strategy & management, sourced online at http://www.xstrata.com/sustainability/environment/climatechange/climatestrategy, accessed 12/9/11

Xstrata (2013). *Sustainability Report*. Accessed online at http://www.glencore.com/assets/Uploads/other/2013-Sustainability-Report.pdf