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Zero Emission Developments

-Towards future sustainable communities

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Thesis for the Degree in Master of Science

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Executive Summary

A raised awareness around climate change has been followed by different initiatives and targets being set around the world to decrease greenhouse gas emissions. Pressure is not only being placed on international and national bodies but also on local communities, industries, businesses and even individual households.

The most prominent international action is the funding of the United Nations Framework Convention on Climate Change, UNFCCC, and the establishment of the Kyoto Protocol. However, local governments, communities and private developers have also realised the need for action in this area. Regions, cities and communities are acting strongly to decrease their emissions and municipalities are leading by example in stimulating a transition from the use of fossil fuels towards renewable energy. To become zero in greenhouse gas emissions is increasingly becoming a common expression for these local actors, resulting in new projects here referred to as 'zero emission developments'

Zero emission developments are generally local projects aiming to create sustainable communities. Local and national governments as well as private developers or organisations can all be part of the establishment. They are aiming for targets which the rest of the world is not even close in attempting to reach. Hence, zero emission developments are extremely important in the phase of moving towards a future relying on renewable energy sources and high energy efficiency, along with decreasing greenhouse pollution. It is vital to document the progress of zero emission developments in order to continue to expand and promote the concept of those developments. This is crucial due to the potential that these developments have to set an example to the rest of the world, showing the future possibilities to create developments which release zero emissions as a part of the actions required to tackle climate change.

Based on the future value seen in zero emission developments there is a need to recognise possible ways of identifying zero emission developments and outline vital steps in the definition process. Moreover, an outline of renewable resources, renewable and efficient technologies and abatement strategies that are available, along with other important considerations when creating a zero emission development, is essential. In addition, the modelling of different scenarios of technology and strategy combinations is vital. Such modelling aims to present a range of options to achieve zero emissions. These scenarios depend on particular goals set out by the project proponent, which may include achieving zero emissions through certain economic goals, social benefits, a particular community environment or specific environmental perspective.

It is found that the definition of a zero emission development is a complex but vital process. It is argued that no universal definition should be developed due to the

variable conditions and opportunities each development has. Instead, it is crucial to each development to create an *individual definition*. An outline involving what is important to consider when defining a zero emission development has been created to guide developers when determining *their* definition. A definition should involve an establishment of suitable *terminology* and clarification of what the terminology involves. Moreover, an *area*, *boundary conditions*, classifying involved energy sectors, and *timeframes* for the emissions accounted for, are crucial elements of a definition.

Suitable renewable energy technologies that have been evaluated for zero emission developments are solar and wind energy, hydroelectric energy and co-generation operating on biofuel. Additional energy efficient technologies discussed are co- and tri-generation operating on natural gas and ground source heat pumps. The importance of passively designed houses for reduced energy demand is presented, and different abatement strategies discussed.

It is argued that the more scenarios that are modelled, with different proposed technologies and strategies, the more likely the project proponents are to find a model which suits the aims and objectives of the particular development. In this thesis a total of four scenarios have been modelled. In reality, four scenarios is probably insufficient for making a decision on which will provide the best outcome in terms of set aims and objectives. Instead the modelling is an attempt to demonstrate a spectrum of possible combinations of technologies and strategies, varying from scenarios with more established energy efficient technologies to those completely relying on renewable energy technologies.

The effect of a future carbon price to those implementations is found to put the scenarios solely depending on renewable energy technologies in a different light. This is particularly evident when calculating the Net Present Value (NPV), involving a carbon price, for the scenarios. The outcome of the calculations shows the importance of including future probable costs for emissions. Furthermore, it is found that to justify high initial costs for future zero emission developments, a price on environmental benefits could be important to consider.

It is concluded that early zero emission developments provide the guidance towards extended implementations. In the future the hope is that these early developments will play a vital role as a guideline to larger and more complex definitions and implementations of zero emission developments. Zero emission developments represent a small-scale application of what hopefully will be the future of all new developments. They are found to establish a learning process for further spreading of implementations, definitions and renewable and efficient energy technologies and abatement strategies. Hence, documentation and guidelines of these early developments are vital to support increasing amount of establishments, and provide an important stepping stone towards a future of more sustainable living.

Preface

This report is the result of research performed for The Moreland Energy Foundation Ltd, MEFL. MEFL is an independent not-for-profit organisation established by the Moreland City Council, to help reduce greenhouse gas emissions across the municipality. A Master Thesis is the final component of a Degree in Mechanical Engineering, Master of Science at the Faculty of Engineering, LTH, at Lund University in Sweden. It is to be carried out over one university semester.

I would like to take this opportunity to thank those who have supported me along the way in my studies. Firstly, I would like to thank Brad Shone, my supervisor at MEFL, for invaluable input and comments, loyal support and always having time for my questions. Your commitment has been incredible. I also greatly appreciate the support and feedback from all MEFL staff, who immediately saw me as part of their organisation, always guiding me in the right direction to find the information I was asking for. Special thanks to Paul Murfitt, Chief Executive Officer at the Moreland Energy Foundation, for making it possible for me to write my thesis with them.

I express my appreciation to my supervisor at Lund University, Jurek Pyrko, for his guidance and support, and for acting as my link to Sweden, enabling me to write my Master Thesis in Melbourne.

Finally, I would also like to thank my family for supporting me throughout my education, always believing in me and in the decisions that I have made. Especially thanks to Jeremy for proofreading my text and always being there when I have been in doubt.

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Malin Lindblad
Melbourne, May 2009

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1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere which is in addition to natural climate variability observed over comparable periods’ (IPCC 2004).

With increasing discussion about climate change and its origin, effect on the earth and human impact on it, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 (IPCC 2004). The IPCC was created to assess the scientific, technical and socio-economic information relevant to understand the scientific risks of human induced climate change. It is today recognised that emissions and aerosols due to human activity continue to alter the atmosphere in ways that are expected to affect the climate, and there is strong evidence that most of the warming over the last 50 years is a result of human activities (IPCC 2004).

Facing increasing population and higher standards of living, environmental strains continue to increase. Our current lifestyle is dependent on the burning of coal, oil and natural gas. Greenhouse gases only make up 1% of the atmosphere, but are acting as a blanket around the earth trapping the heat. Carbon dioxide is the most prominent greenhouse gas, and currently the amount of CO_2 in the atmosphere is increasing by over 10% every 20 years. The natural levels of the greenhouse gases are today supplemented by emissions of carbon dioxide when burning coal, oil and natural gas. Moreover, farming activities and change of land-use both result in additional greenhouse gases such as methane and nitrous dioxide (UNFCCC 2009d).

The raised awareness around climate change has been followed by different initiatives and targets being set around the world to decrease greenhouse gas emissions. The pressure is not only being placed on international and national bodies but also on local communities, industries, businesses and even individual households to replace fossil fuel based energy sources with more renewable energy sources.

The most prominent international action is the funding of UNFCCC and the establishment of the Kyoto Protocol. The first assessment of the IPCC served as the basis for negotiating the UNFCCC (IPCC 2004).

The treaty involves legally binding measures of greenhouse gases (UNFCCC 2009a) and 184 parties of the convention have ratified the protocol to date (UNFCCC 2009b). Targets for the initial timeframe and for different countries which have ratified the protocol vary between an 8% decrease to a 10% increase of 1990’s emissions (UNFCCC 2009c).

On a local scale, the aim for a more sustainable future seems to go beyond those goals of the Kyoto target and other national and international attempts to attack climate change. Local governments, communities or private developers have realised the need for action in this area and are leading by example in developing a range of strategies to address climate change and other environmental issues (Bates, Hamilton et al. 2008). Regions, cities and communities are the ones acting strongly to enable new and existing developments to decrease their emissions and municipalities are fast becoming the main actors in stimulating a transition from the use of fossil fuels towards renewable energy (Rovers and Rovers 2008). Instead of aiming to decrease their emissions, the goal is to release no emissions at all. To become zero in emissions is increasingly becoming a common expression for these local actors resulting in new projects here referred to as ‘zero emission developments’.

1.1 Background

Zero emission developments are generally local projects aiming to create sustainable communities. However, local and national governments, as well as private developers or organisations can all be part of the establishment.

In order to tackle climate change by reducing greenhouse gases, those developments have a strong focus on available renewable energy sources and technologies. Moreover, efficient housing design and energy management is a key aspect in zero emission developments as well as promoting the possibility of sustainable living without sacrificing the comfort of its inhabitants.

Renewable energy, or renewables, is different energy sources which are sustainable within a short time frame, compared to the earth’s natural cycles. They include non-carbon technologies such as solar energy, wind energy and hydropower. Also technologies based on the use of biomass are renewable energy or renewables (IPCC 2001). Renewable energy can be applied in different ways in zero emission developments. Even if these renewable sources and technologies are globally available, not all of them can be captured for use locally (Hamilton 2008). Reasons for this may include: policies and regulations around the area; low level of a particular source in the area; issues with storage or transfer of energy to areas of demand; lack of developed technology at required energy level; or comparatively high costs for implementation. A combination of renewables can be utilised to enable a zero emission development. The ultimate combination of technologies and other applications is highly dependent on the site of implementation.

Zero emission developments can be carried out at different locations, under varying circumstances and conditions and at different scales. Such situation makes an establishment of a set definition to zero emission developments difficult. In this thesis it is argued that one single definition should not be created. Instead the implementation and planning process is site and condition dependent, and a definition has to be prepared for each individual location. However, there are *common features* of implementations, considerations and issues which can be described. Similarly guidelines to the establishment of a definition and types of definitions can be discussed and options of definitions made available.

Zero emission developments are aiming for targets which we internationally are not even close in attempting to reach. They are hence extremely important in the phase of moving towards a future relying on renewable energy sources and high energy efficiency along with decreasing greenhouse pollution. Small scale developments are vital in the learning process of how a zero emission future may be carried out. With every new implemented development new lessons are learned and more knowledge of renewable energy sources, technologies and well implemented development strategies are achieved.

Even though individual definitions and implementation plans should be established for each development, there are common features both in terms of definitions and implementation possibilities. Based on the future value seen in zero emission developments there is a need to recognise possible ways of identifying zero emission developments and outline vital steps in the definition process. Moreover, an outline of renewable resources, renewable and efficient technologies and abatement strategies that are available, along with other important considerations and possible development scenarios when creating a zero emission development, is essential.

1.2 Methods

The idea of this thesis evolved from discussions with the employees at the Moreland Energy Foundation Ltd. Reading and hearing about a variety of sustainable projects such as zero emission developments, it was realised that many of these projects were developed under different definitions and terminology. Moreover, sometimes similar terminology was used, but different aims and objectives were behind the definition. This created an awareness of the wide range of existing ways of defining these types of developments and also the lack of definition for many projects.

However, it was recognised early that with zero emission developments having global potential and being implemented in locations with completely different opportunities and conditions, no one set definition could or should be developed. Instead, developers need tools and guidelines for how their specific development can be defined and implemented.

From that idea, the thesis was decided to involve clarification, discussion and descriptions of ways to define zero emission developments. Such description is made to stress the importance of a definition and for the definition to be individually applied to the specific development. Guidelines for both definitions and implementations for zero emission developments are important to enable future replicability. It was found that an outline of possible renewable energy sources and technologies would be beneficial for a developer, along with additional requirements to become a successful development. Furthermore, a development is more likely to succeed after viewing different combinations of technologies to find the most suitable for the particular location. Hence the concept of scenario development was decided to be of importance to demonstrate; different possible combinations, cost and benefit comparisons and the planning process of a scenario.

Initially, case studies on already existing developments were performed to collect information and detect similarities and differences in definition, renewable technologies, implementation and outcomes. Some case studies are outlined in this thesis. In addition, the Moreland Energy Foundation Ltd is currently part of a government funded project called Solar Cities, involving a zero emission development approach, providing ideas of possible technologies. Through this, an idea of renewable energy technologies, energy efficient technologies and emission abatement strategies available for zero emission developments, was created. Research on the different technologies was performed, and is presented in the thesis.

There are obviously further factors which will have an impact on the progress and success of the development. Again, the Moreland Energy Foundation Ltd is strongly engaged in community based sustainability work and recognises the significance of community awareness and involvement to properly implement environmental work. The importance of social and cultural awareness is hence discussed. Costs and benefits along with policy context in different countries will also have an impact on the development and are part of the core factors affecting the outcome.

Through the Moreland Energy Foundation’s involvement in the Solar Cities project, they are currently in the process of suggesting renewable energy technologies and different scenario combinations of those technologies to developers of an urban infill development in Melbourne. The scenarios are to be based on an energy assessment of the proposed development, and will involve different combinations of technology to provide the locally most suitable solution. With this in mind, an energy assessment and scenario modelling were realised to be important parts in the planning process of a zero emission development.

For this thesis, four different scenarios have been created based on a simplified energy assessment. Firstly, the energy demand for a hypothetical development was based on estimated energy demand in efficient energy or passively designed houses. The costs and energy outputs for the different technologies were then researched. It was realised that those costs and outputs are often location dependent. For some technologies, such as the ones based on solar energy, a location had to be chosen for an approximate possible solar output. Since the research was performed in Melbourne, this was the chosen location for solar data. For other estimates requiring a specific location Melbourne, Victoria or Australia is used as a baseline.

To provide the development scenario with the right energy output, both costs and energy and electricity outputs had to be recalculated. All calculations were performed in Excel and costs and outputs were based on research and also on information from employees at the Moreland Energy Foundation Ltd and experts within the technological fields when required.

Similarly to the definition of a zero emission development, cost and output estimations have to be made individually for each development. However, the modelled scenarios provide a good idea of combinations to consider or not to consider. It also indicates which technologies might be more expensive and the benefits of the technologies and their combinations are discussed.

Throughout the research on zero emission developments, the definitions, renewable and efficient energy technologies and abatement strategies, possible combinations of scenarios and case studies and several issues with those implementations have been identified. However, the potential that these developments have to set an example to the rest of the world, showing the future possibilities to create developments which release zero emissions, outweighs those issues. Hence, it is vital to document this in order for those developments to continue their work and promote the concept of zero emissions developments. Both successful and unsuccessful developments provide a lesson and enable future projects to improve.

2 Aims and Objectives

The aim of this thesis is to provide a discussion around possibilities and issues involving the planning and implementation of a zero emission development. The objectives required to meet this aim are as follows:

- ✓ Discuss the different possible definitions of and approaches to zero emission developments.
- ✓ Discuss the importance of properly defining each individual development.
- ✓ Define a zero emission development approach appropriate for this thesis.
- ✓ Present an outline of how to achieve the defined zero emission development through:
  - » Review the available renewable resources.
  - » Discuss the available renewable and efficient energy technologies, along with appropriate abatement strategies.
  - » Present the additional requirements to enable a successful development strategy.
  - » Prepare an energy assessment and then compare possible development scenarios from an environmental and economic perspective.
  - » Perform case studies on existing developments.
  - » Where possible, discuss the Australian conditions for implementation.
- ✓ Discuss the issues and constraints along with future possibilities for zero emission developments.

2.1 Limitations

This thesis does not aim to provide one set definition to zero emission development. Rather it is limited to an attempt to discuss the complexity behind defining these developments and provide examples of definitions and to stress the importance of having an initial clear definition.

To simplify the presented outline of how to achieve the defined zero emission development, the definition proposed for this thesis is limited to an operational net zero emission development. It is further set to achieve zero net emissions from operational stationary energy use only, on an annual basis, which allows for in and export of energy. The definition will be discussed closer in the following chapter. The reason for the limitations in the definition is to enable a well established discussion on the actions required for the defined zero emission development. Moreover it represents what a large amount of developments have the capability of achieving today in terms of being zero emissions. It can be seen as an initial strategy to facilitate the work towards a more sustainable future.

There are also limitations in the scenario modelling cost and benefit analysis. Estimated costs are greatly limited depending on assumptions made, and costs are highly likely to vary with each development. The modelling is limited to provide a good estimation of which scenario is more expensive in comparison to another, as well as benefits gained and issues raised for each set scenario.

In total, four scenarios are modelled. To that few scenarios is generally not sufficient before a decision on which will provide the best outcome in terms of set aim and objectives. Instead these four scenarios are limited to present a spectrum of combinations that could be suggested. They range from being completely dependent on renewable energy technologies, to the use of a well established technology such as gas fired co-generation, paying to offset the produced emissions.

3 Defining Zero Emission Developments

As described, awareness around climate change and enhanced greenhouse effect is today followed by a great deal of initiatives to reduce greenhouse gas emissions and increase the supply of renewable energy. Developments or projects claim to be 'climate neutral', 'zero emissions', 'net zero carbon' or '100% renewable' when expressing the aim of environmental developments, in an attempt to reduce greenhouse pollution and act against climate change. These expressions involve a wide range of claims with or without clear definitions on what it actually encompasses to be 'zero emissions' or 'climate neutral'. They imply that developers dealing with environmental projects such as zero emission developments have no well developed definition framework to work from in an initial stage of their project.

This chapter provides a discussion about different examples of definitions and the complexity involved in defining zero emission developments. It aims to show that with zero emission developments having global potential and being implemented in locations with completely different opportunities and conditions, no one set definition could or should be developed. Instead the importance of a clear definition of each individual development is stressed and a discussion on what to consider when defining a zero emission development is provided. This discussion involves decisions around terminology and area as well as defining timeframes, boundary conditions, aims and objectives for the proposed development. Also, the definition used for this thesis will be presented, so that it is clear what type of development the later presented outline considers.

3.1 Terminology

Examples of terms that can be seen in the literature about sustainable developments are:

- ✓ Climate neutral over a one year basis
- ✓ Greenhouse gas neutral development
- ✓ Carbon neutral community
- ✓ Zero (fossil) energy development
- ✓ Zero carbon development
- ✓ Zero emission development
- ✓ Zero emission neighbourhood
- ✓ Climate neutral city
- ✓ 100% Renewable
- ✓ Energy neutral community
- ✓ Energy positive operational site

There is a wide range of terms for different existing and proposed sustainable developments. The terminology can be divided into sources and targets. The source is what is to be decrease or eliminated, whereas the target expresses how the source will be tackled.

The source aimed to decrease or eliminate can be ‘carbon’, ‘emissions’, ‘CO_2’ or ‘greenhouse gases’. A source can also be expressed as ‘climate’ or ‘energy’. Moreover, the targets to eliminate the source can be ‘zero’, ‘net zero’ or ‘neutral’. The words ‘renewable’, ‘100%’ or ‘free’ can also be targets used to explain how the sources are aimed to be tackled.

It can be argued that some terminology is better than other. Rovers and Rovers argue in their report ‘0-energy or Carbon neutral?: Systems and definitions’ that the word carbon can be misleading, since it is part of many other processes, for example forest growth. However, their study also found that carbon stands for CO_2 in almost all environmental studies, and if that is defined the term carbon is workable. It is further discussed that the term emissions is vague, and the included emissions have to be specified. CO_2 as a term in itself is fairly straight forward, but needs definition in terms of including other emissions re-calculated to CO_2 equivalence.

The term climate is probably the vaguest definition on the source and it is very hard to specify what it involves. It implies to involve more than just emissions and project proponents should be careful using this term, unless having a specific thought behind it. However, climate generally refers to climate change and hence the affecting emissions. With that in mind, the term climate could be part of an effective definition if the developer wants to stress the actions taken on climate change. The implication of climate then obviously has to be properly defined.

Similarly energy is quite a broad definition and zero energy sounds like it would exclude all activity from the development, which is not always the case. Furthermore, the term needs a specification of what type of energy it refers to; there is a big difference if it involves renewable energy compared to fossil fuels (Rovers and Rovers 2008).

A standard way to define what the source actually involves could be based on the definition of greenhouse gases which are required to be reported on by the UNFCCC. UNFCCC do require that countries report on their emissions of carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons and sulphur hexafluoride (UNFCCC 2009c). To enable a standard way of measuring those greenhouse gases, they are generally expressed in tonnes of carbon dioxide equivalence (CO_{2e}) based on their global warming potential (see chapter 4.9 for more details).

The targets all aim to balance the situation for demand and supply (Rovers and Rovers 2008). The balance leads in to the definition of being ‘net zero’ or ‘net neutral’. The term net generally refers to eliminating the source over a certain time period, having no net increase in released emissions. This can be compared to be zero emissions at every instance. Having no *net* impact on released emissions can be achieved through utilising:

- ✓ On site renewable technologies
- ✓ Offsetting emissions
- ✓ The utilisation of offsite renewable energy
- ✓ Importing energy when insufficient onsite and exporting excess renewable energy produced onsite (one type of offsetting).
  (Rovers and Rovers 2008)

When outside resources can be utilised, energy can be imported from the national electricity grid when the site does not produce sufficient amounts, but then excess renewable energy or electricity has to be fed into the grid or sold to outside areas to balance the net emissions. In addition, sites may also find that offsetting produced emissions through different offsetting methods is a good way to annually produce zero net emissions. Offsetting emissions is not always ultimate, and it can be discussed and argued that offsetting is not long term sustainable if a wide range of these types of developments evolve. Moreover, offsetting rules and regulations vary across international and national borders, which may create doubts whether the development actually create zero emissions over the set time period or not.

Both zero and neutral can express the aim to release no emissions at all. However, if they are combined with the term net, the developments could still release emissions, as long as they make sure these emissions are balanced so there are no emissions over a certain time period.

Being 100% generally refers to 100% renewable and involves a stronger focus on in what way the source is to be eliminated. A development aiming to be 100% renewable could still work on a net basis, importing energy when not sufficiently produced onsite and export excess energy to balance its emissions over a set time. The developer would still need to specify if the renewable energy is to be produced onsite only or if import of renewable or non-renewable energy is allowed (Rovers and Rovers 2008).

There is obviously a collection of sources and targets which can be used to describe these types of developments. The aim of the above discussion is to show the importance for the developers to evaluate the terms they want to use, and then properly state what the chosen terminology stands for.

In this thesis the terminology zero net emissions will be used. ‘Emissions’ refer to greenhouse gas emissions and the earlier mentioned definition by the UNFCCC. Net zero refers to releasing no net emissions on a one year basis. Different offsetting methods of the emissions will be included in the presented scenarios.

3.2 Development Areas

The area within which the development is to be established also has to be defined. This is generally the least complicated process (Rovers and Rovers 2008). Specifying the area can include a community, city or a region. However, another way of expressing the area is to determine if it is set in greenfield, brownfield, urban infill or precinct.

Greenfields are defined as areas which are initially undeveloped, except for agricultural use. It can also be forests or wetlands, often existing outside of cities or on the urban fringes. Land referred to as greenfields are especially those which are considered as sites for expanding urban development (Wedding and Crawford-Brown 2007).

In contrast to greenfields, brownfields are generally described as land which has previously been under occupation. A brownfield site would be recognised as a site which is presently vacant or underutilised *within* an existing urban development. Brownfield sites are most likely to be sites where there is a risk for contamination from earlier use, and need to be rehabilitated before being reused (Lesage, Ekvall et al. 2007).

An urban infill also exists within an urban development. Urban infill can be a site earlier used for buildings but it can also be an unused green area within the community. It is sometimes defined as underutilised land and buildings and differs from a brownfield in the sense that there is no need for rehabilitation of the ground (Miodonski 2006).

A precinct is expanded to include other parts of a city or a region as well. The precinct is defined more as a multi-use area within certain boundaries (Farlex 2009). In terms of zero emission developments, a precinct generally involves both an area of existing buildings and an area on which the new development will take place.

Certain benefits can be seen in using a precinct as the defined area. Firstly, it avoids creating green belts around cities, which could happen if these types of projects were set in a greenfield area outside a city or region. Moreover, with expanding population it is of paramount importance to efficiently use as much underutilised land, such as brownfields or urban infills, as possible. Taking a step further involving a whole precinct in the development enables the involvement of existing buildings and communities to further promote sustainability. Nevertheless, developments in all these types of areas should be encouraged. There are instances where a greenfield development might be the most suitable option.

In this thesis, the outline proposed technologies, strategies and scenarios will apply to all the defined areas.

3.3 Boundary Conditions

It is crucial to define exactly which emission sources are being discussed. Energy is used in a wide range of sectors, all having an impact on the released emissions. It has to be decided which of those sectors are accounted for within the development.

Energy sectors to consider are shown below:

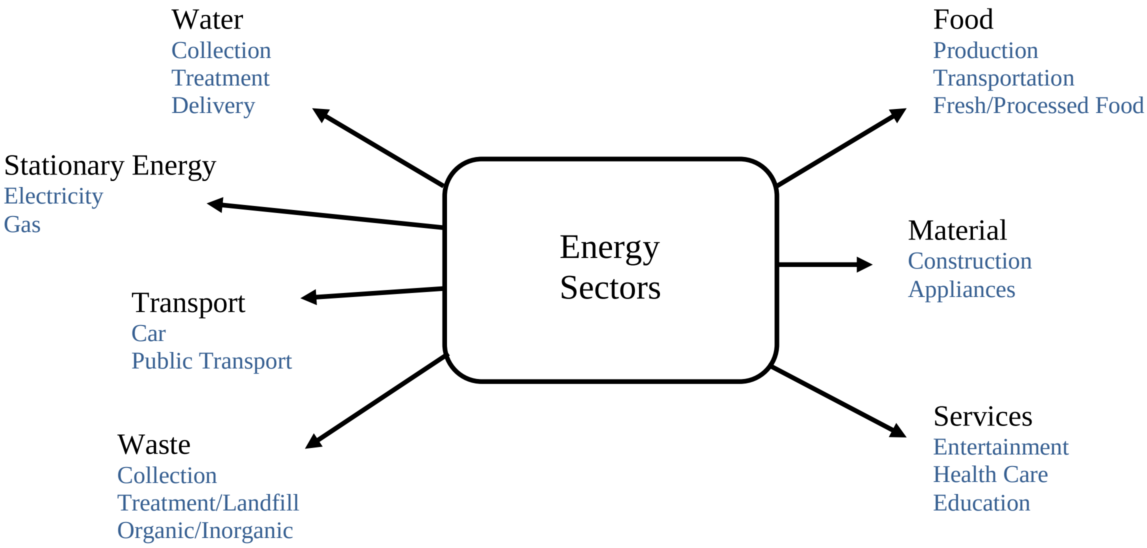

Figure 1: Examples of energy sectors

The stationary energy is energy used for heating, hot water, cooling, ventilation, lighting, cooking, appliances, computers, lifts, etc in existing buildings. Such energy use is the easiest to measure and hence generally the first to include when estimating emissions.

Energy and emissions related to materials is also relatively easy to estimate and related to embodied energy from construction and transportation of material and appliances. For transport, water, waste and food, quantification, assignment and reduction of emissions however become far more complex. For these energy sectors, emissions are more closely related to factors which are harder to control, such as human behaviour and occurrences outside of the precinct boundaries.

It has to be defined for each sector if it is accounted for and how, since claiming being a zero emission development if only buildings are addressed is completely different from when energy for waste, water or transport is included (Rovers and Rovers 2008). As mentioned, considering emissions from stationary energy is generally the initial step. Moreover, there are sustainable trends working for reductions in energy use within the water, waste and transport sector are often considered along with decreased energy use throughout the construction.

The included energy sectors determine the complexity of the development, which can be seen as levels of implementation. At an initial stage only operational stationary energy may be accounted for. However, including the emissions from construction, recycling and demolition of the built site further includes the life cycle emissions from the stationary energy. This obviously results in increased complexity of the development. Further actions to take could be including additional energy sectors or even sustainability as a whole concept. The triangle presented below is one way of visualising the level of emissions accounted for:

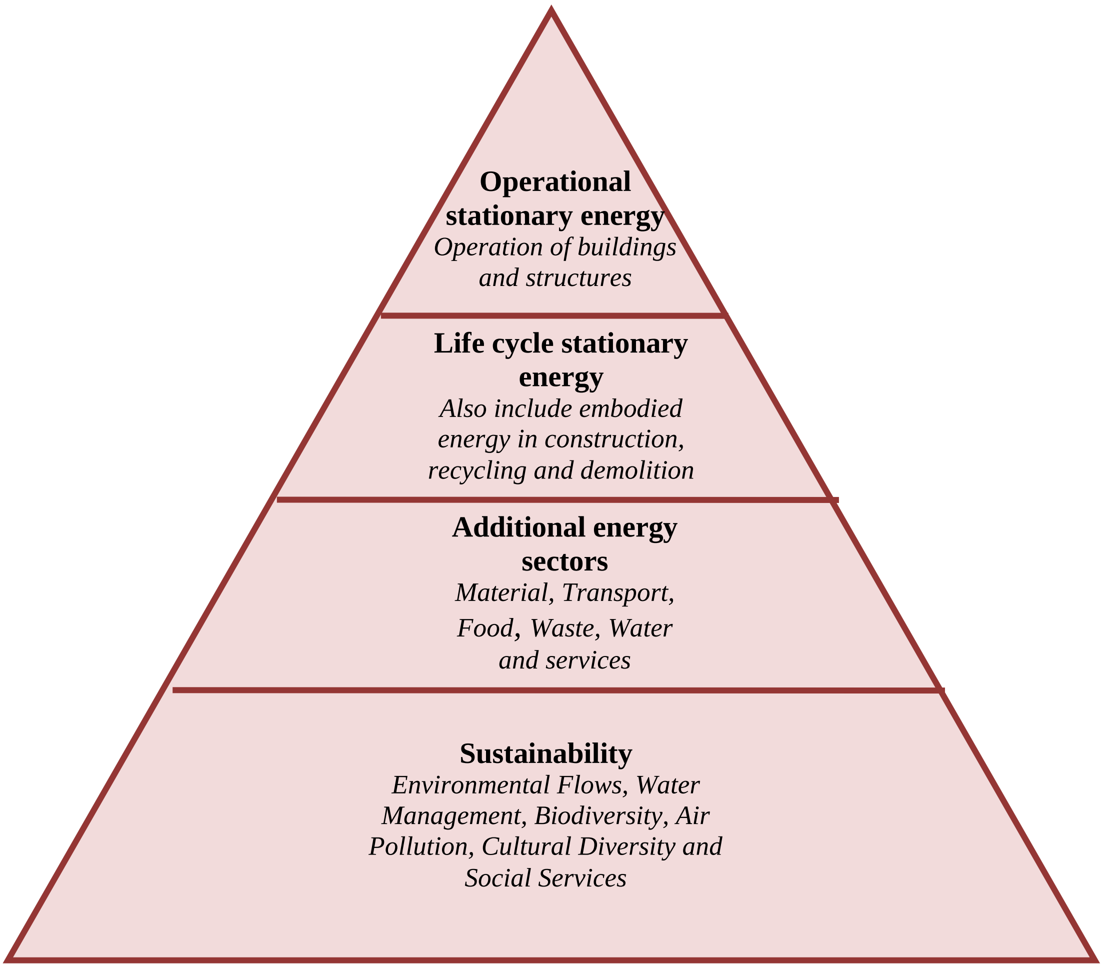

Figure 2: Levels of greenhouse gas emissions in a zero emission development

Figure two shows the stationary energy at the top of the triangle, expanding out to include all emissions involving sustainability at the bottom. Trying to reduce emissions from additional energy sectors and including life cycle energy enables developments to slowly work their way down the triangle. It is important to stress that creating developments from a sustainable perspective involves much more than just trying to decrease emissions. Rather, zero emissions should be one of the concepts that sustainability involves.

Where operational stationary energy use within a set development is relatively easy to calculate, and provide renewable energy for. It becomes more complicated when including life cycle energy for the construction of the site and even more complex when including sectors such as transport, waste, water or sustainability as a whole. To include all these factors into a development requires extensive work, involving definitions of what sustainability means to, and how it can be achieved in, the particular area of implementation. It is obvious the more sectors that are included in the definition, the more emissions are considered and hence greater impacts can be reduced. Each additional included sector does however involve more extensive research.

In this thesis the boundary conditions only involve operational energy use. This is to properly be able to report on the required actions for the defined zero emission development.

3.4 Timeframes

When terminology, area and boundary conditions are defined, developers have to consider in what way they aim being, in this case, zero net emissions. One way of looking at it is to define if the development aims to be:

- ✓ Operational net zero
- ✓ Life cycle net zero
- ✓ Life cycle net negative

  (Preuss 2009)

Preuss (2009) define life cycle emissions to include sourcing, manufacturing and transporting material, emissions during construction, operational emissions, emissions from renovations and demolition and reuse.

The graph below shows the emissions for each of these cases compared with a business as usual:

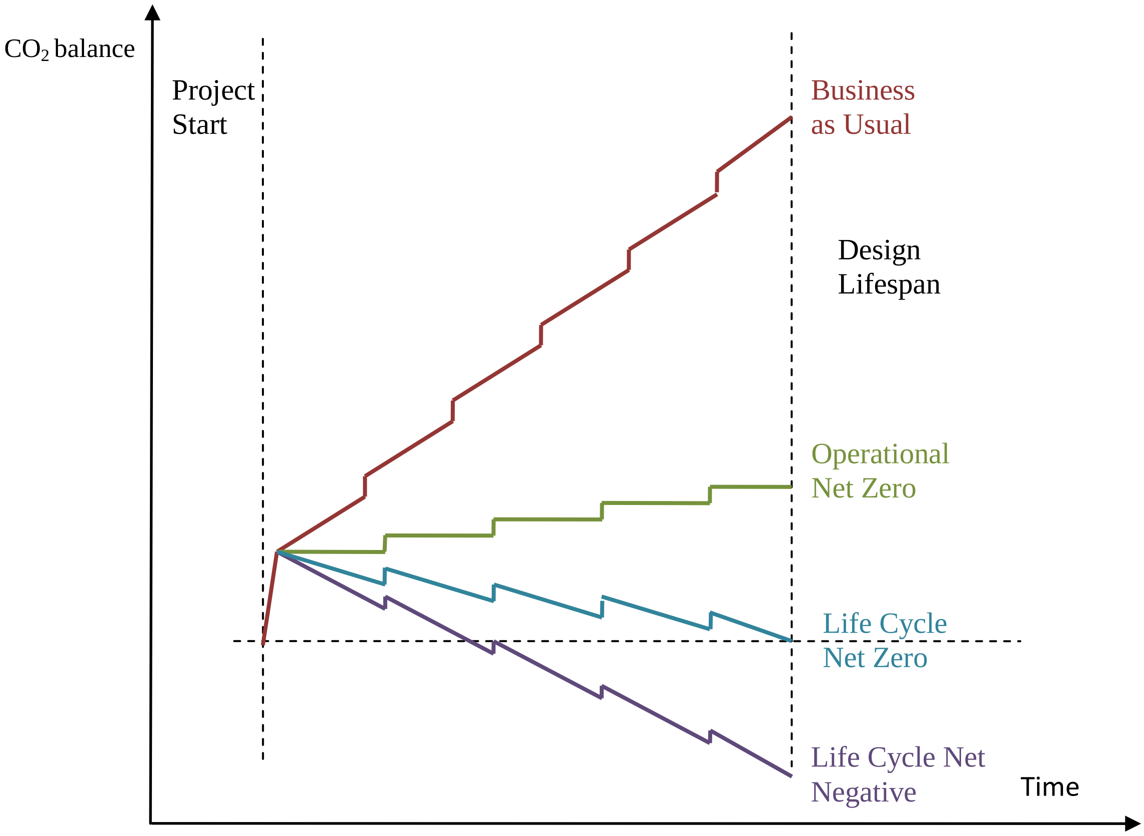

Figure 3: Boundary condition cases (Preuss 2009)

The initial red line represents the embodied energy during construction and in material for the different cases. Every vertical increase in emissions is based on embodied energy due to renovations required for the buildings.

For the development to be *operational net zero* it only means that the operational phase results in no added greenhouse gas emissions to the atmosphere. However, if renovation is performed it may involve extra emissions. Operational net zero developments will have a strong focus on energy efficiency of buildings and the use of onsite renewable and efficient energy technologies.

If instead the aim is to be *life cycle net zero*, the development includes the energy from construction and embodied energy. To achieve this, offsetting is required of the life span emissions to achieve no emissions compared to before the construction of the development.

Being *life cycle net negative* involves producing more renewable energy than used throughout the life time of the development, or offsetting the emissions in another way, to decrease the emissions compared to before the implementation.

These examples are not the only definitions available, but they do give an overview of to what extent a development can become zero emissions, and how different the concept of being zero emissions can be depending on how the emissions are accounted for.

According to Preuss (2009), the embodied emissions from the construction phase takes up about 15% of the total energy use of a building. As developments focus more on decreasing the operational use, the initial construction and embodied energy will become a greater percentage of the life cycle energy use. With today's estimate around 40% of the life cycle energy use is embodied energy in an energy efficient building which will hopefully evolve into a stronger focus on being life cycle net zero by newly established developers.

In this thesis the outline considers both operational net zero emissions, life cycle net zero and life cycle net negative developments. However, the scenario modelling is based on an operational net zero approach, but can apply to both life cycle net zero and life cycle net negative if considering extended investment in producing energy from renewable or efficient technologies or additional abatement strategies for greenhouse gas emissions, to offset the initial building energy.

3.5 Thesis Zero Emission Development Definition

This thesis aims to outline a zero emission development defined as an operational net zero emission development. It is defined to achieve zero net emissions from operational stationary energy use on site, on an annual basis. Energy use on site relates to all energy uses of buildings and structures, and what goes on within them. These uses are heating, hot water, cooling, ventilation, lighting, cooking, appliances, computers, lifts, etc. The development is thought to be grid connected allowing for import and export of electricity. Some scenarios will include offsetting, and others not and issues with offsetting will be covered. The aim is to outline how the defined zero emission development can be achieved by discussing available technologies, strategies and possible scenarios.

Also, additional requirements for a successful development will be considered. It is aimed to be an initial strategy to facilitate in work towards a more sustainable future. The definition may be limited if comparing to other possible definitions. Such limitations are made to enable a well established discussion on the actions required for the defined zero emission development. The guide to implement the defined zero emission development can very well be expanded to fit more extensive definitions in the future.

The definition is summarised in table 1 below;

Table 1: The defined zero emission development

Type of Definition	Definition	Comments
Terminology	Zero emissions	Emissions are greenhouse gases which are required to be reported by the UNFCCC
Area	Brownfield/ Precinct/ Urban Infill/ Greenfield	All areas possible
Boundaries	Stationary energy	
Boundaries	Net zero on an annual basis	Offsetting and importing energy allowed
Timeframe	Operational net zero emissions	Could apply to other timeframes as well

This chapter shows the complexity involved with defining a zero emission development. There is a wide range of definitions and developments on many different levels. Hence no universal definition can or should be developed. Instead it is crucial to each development to create an individual definition. This definition should be thoroughly worked through and it should be clearly stated what is involved in becoming a zero emission development.

A definition suitable for this thesis has been proposed. The defined zero emission development is not claimed to be an ultimate definition, instead it is created to enable a well developed outline for this thesis. The outline can be applied to all the areas discussed, and for life cycle net zero or life cycle net negative developments as well, if extended investments in energy production from renewable or efficient technologies, or extended abatement strategies, are made. To involve extensive boundary conditions such as water, transport or waste, extended research is required.

4 Selecting the Right Technologies and Abatement Strategies

Determining the appropriate technologies for a zero emission development is a vital part of the process. This chapter presents a discussion about initial energy assessment requirements and it also provides a range of examples of renewable energy and energy efficient technologies which can be considered in the selection process. Technologies and designs discussed are passive design of buildings, solar energy technologies, wind energy technologies, co-generation, tri-generation, hydroelectric technology and heat pumps. Possible abatement strategies proposed are carbon offsetting through for example retrofitting of old buildings. These are described and issues, constraints, costs and benefits are discussed. The technologies are chosen to support the defined zero emission development.

In Australia particularly investment costs may be decreased through Renewable Energy Certificates (RECs). Anyone installing Small Generation Units (SGUs) of renewable energy are eligible for RECs. The limitation varies depending on the renewable energy technology, giving RECs to installations up to 10 kW or a generation output of less than 25 MWh for wind, 100 kW or 250 MWh for solar (photovoltaic) systems or 6.4 kW or 25MWh for hydro. Money can be received for up to 15 years in advance for solar, and for periods up to five years for all the technologies, based on an estimated energy production of the specific renewable energy technology. There is, however, a concern that when selling the RECs, all that the individual installers will do is to add to the proposed Renewable Energy Target (RET) of 20% that Australia has, and hence individual actions are not accounted for (Australian Government 2008c).

4.1 Energy Assessment

Before evaluating the renewable energy sources and technologies suitable for the defined area of development an energy assessment should be performed. This enables the project proponents to determine approximate energy requirements for the future development. Locally relevant baseline energy data is essential to enable the identification of appropriate emissions reductions mechanisms. This knowledge also informs the developer of relevant targets and provides the base for measuring the effectiveness of the chosen methods.

If the development covers a precinct with already existing buildings, the energy assessment involves collecting information about the energy use for those dwellings and businesses. Such information is vital to investigate if retrofitting of these buildings is possible. A decrease in energy use through retrofitting could offset energy used in the area with new buildings, and assist in reaching zero net emissions for the whole precinct.

Energy assessment and collection of energy use information generally requires collaboration with existing local energy distributors and retailers. A complex part of mapping the energy consumption throughout the community and precinct is to locate the benefits for each party involved. Particularly the distributers and retailers may struggle to find value in sharing their information, since the implementation of the zero emission development may very well decrease the required energy output from them. However, it is important to stress their opportunity in being part of a large re-development with a strong environmental focus enables them to show their commitment to a more sustainable future. Likewise, if the development is planned to go ahead, it should be in the energy company's interest to be a part of such development rather than being a competitor when developing new solutions to expanding demand management.

4.2 Passive Design

Passive design of a house is vital when creating a zero emission development. Utilising the possibility to lower the energy use of the whole development through passive design building will facilitate the process of having net zero emissions.

Passive design is design which in theory does not require mechanical heating or cooling. However, this varies, particularly in very warm areas, where additional cooling may be required. Homes with passive design take advantage of natural climate to maintain thermal comfort. Well designed homes utilise the heat from the sun by trapping and storing it in winter. In summer, they maximise cooling air movement through the house and exclude the sun. Passive design depends on a combination of different design principles such as location and orientation of the house, proper shading, solar heating, passive cooling and ventilation, insulation, proper glazing and the utilisation of thermal mass. It is also heavily dependent on the climate at the specific site (Reardon 2008a).

4.2.1 Climate

The tilt of the Earth's axis as it is orbiting the sun creates different paths and angles of the sun in winter and summer. Such paths and angles differ depending on the location on Earth, and hence needs to be considered to achieve the ultimate passive design. Information about the suns location at any time of the year is useful for calculating the proper location and orientation of the house as well as size of overhang and windows for ultimate heating and cooling outcome (SEAV 2002).

Australia has quite a broad range of climate conditions. There are many definitions of Australia's climate zones. The Building Code of Australia (BCA) defines eight zones, ranging from highly humid summers and warm winters in the north and hot and dry summers and warm winters in the centre to hot and dry summers and cool winters as well as cool temperate zones in the south (Reardon 2008b). Even though those climate zones are quite variable, there are passive design principles to suit them all.

4.2.2 Site, Location and Orientation

Good solar access for new housing depends largely on the chosen site. The energy efficient housing can be provided more easily if the home is sited with good solar access. Characteristics such as orientation, slope, size and shape of the site and potential overshadowing are all important (SEAV 2002) hence choosing the right lot and correctly placing the home is fundamental to the design process.

In Australia, located in the southern hemisphere, ideally homes should be placed so that living areas and major windows face north. No large trees or fences should be obstructing in the northern direction to maximise the use of winter sun for warmth and light. However, if solar access is poor during winter time, there are still opportunities for energy efficient design. Alternative methods to gain northerly sunlight into the home exist, such as using highly placed, so called clerestory windows (SEAV 2002).

The location of rooms inside the house will also affect the energy efficiency of the house. There is a range of different guidelines regarding inside location and orientation of rooms, walls, ceilings and stairs. Rooms with similar uses should be grouped together, such as bedrooms. In that way heating or cooling for that particular zone is made more efficient. Doors should be used to properly separate heated areas from unheated areas. Areas that use hot water, such as bathroom and laundry, should be lumped together to minimise heat loss and ceilings heights should be kept as low as possible.

4.2.3 Windows and Glazing

Windows are important in any type of home design. They provide natural light, fresh air and views for the residents. It is however, an even more important component in terms of passive design, since both heat loss and gain in a well insulated house occurs mainly through windows (Reardon 2008a). A well designed and protected window will improve the indoor comfort by reducing or avoiding the need for heating in winter and cooling in summer (SEAV 2002).

The three main parts of window design are: to maximise the heat gain by orientating windows to the north and size the windows to suit the thermal mass for heat storage in the dwelling; to minimise the heat loss through the right sizing of the window and double glazing; and to minimise heat gain in summer by protecting the window with external shading (SEAV 2002). As shortwave radiation from the sun passes through the window it is absorbed by furniture and other building elements and re- radiate the heat into the room. The re- radiated heat is longwave radiation, which cannot pass through the window again due to a loss in energy as a result of the rays bouncing of the floor or the walls and passing through the window. Hence, the house is warmed up. Such effect should be utilised in winter, but avoided in summer. In addition, the house loses heat through convection, if the air outside is cooler. This is an issue at night time, especially in winter. It is important that the building is designed so that there is a net heat gain in winter, i.e. the gained heat from the suns radiation is larger than the heat lost through convection. Similarly, the aim should be a net heat loss in summer.

4.2.4 Shading

Proper shading in summer is significant for a well functioning passive design house. Since the shaded window often needs access to the sunlight in winter, shading needs to be removable or non-existent at that time.

Plants and trees are one option of shading used. In areas where winter sunlight is required, any type of deciduous plants which are green and covering in summer but not blocking the sun in winter should be used. In very hot climates, evergreen plants may be utilised. The use of external shading devices is also encouraged, where internal shading will only reduce heat gain if they are reflective. There are also more advanced glazing solutions such as solar films or tinted glass, which should especially be utilised on less exposed east and west facing windows (Reardon 2008c).

Good external shading is also required for clerestory windows using overhanging eaves and for skylights using blinds (Reardon 2008c).

4.2.5 Thermal Mass

The heat gained through solar radiation has to be properly stored to be released when required. Dense materials such as concrete, bricks and other masonry are used in passive design to absorb, store and re-release the thermal energy (Reardon 2008a). The thermal mass describes the ability of a building material to absorb heat. It is generally installed as a wall inside the house to create a more moderate indoor temperature all year around.

In summer, the thermal mass absorbs heat from within the house. Since it is at a lower temperature than the surroundings, it operates as a sink, lowering the temperature in the house. At night, the heat is slowly released either straight back into the room, dumped to cooler breezes due to natural ventilation or extracted by exhaust fans. In winter, the thermal mass absorbs the heat from the sun. It is vital that the thermal mass is directly exposed to the sun entering the house through the north facing windows. The heat gained is then slowly released back into the room throughout night, reducing the need for additional heating (SEAV 2002).

There are different possible locations of the thermal mass. It could be placed inside insulated walls, as a concrete slab in the ground or inside north facing rooms. Fireplaces can also act as a thermal mass, especially if placed in internal rather than external walls (SEAV 2002).

4.2.6 Insulation

Insulation is another essential component in passive design. It minimises heat loss and heat gain through walls, roofs and floors (Reardon 2008a). Insulating material refers to material which provides substantial resistance to heat flow. By insulating floors, walls and ceilings, the heat flow in and out of the building is dramatically decreased. There are a wide range of different insulation materials, and the preferred material is for example based on: the performance in restricting heat needed for the particular area; the availability of certain materials; if the material is appropriate for the intended insulation; and standards set by testing authorities in different countries and local building authorities (SEAV 2002).

Insulation needs to be coupled with proper ventilation of air and also the earlier discussed shading of windows. The need for insulation may also be decreased if walls are shared with neighbours and houses are more compactly built.

4.2.7 Ventilation/Air Movement

The control of air movement include reduction of uncontrolled air leakage and controlled ventilation, are both essential to minimise the need for additional heating and cooling.

Reduction in air leakage will prevent heat loss in winter and prevent hot air to enter during summer. Leakage can be minimised with particular attention to design, detailing, specification and construction. Typical sources of heat loss are windows and external doors, construction gaps, open fireplaces, non- sealable exhaust fans and unsealed duct outlets. Considering these sources in the construction phase will reduce the air leakage of the building. If leakage is detected after construction, drought proofing is a fairly easy implementation which will reduce air leakage significantly (SEAV 2002).

Controlled ventilation is fairly simple and can be incorporated into the passive design of the house. Ventilation is important to maintain adequate air quality especially in areas such as bathrooms and kitchens. This is particularly important in a house with high air tightness and insulation, which is generally the case in passively designed houses. It is based replacing warm inside air with cooler outside air by utilising naturally occurring air temperature and pressure differences. There are a few different principles of cooling through ventilation in use. Convection can be used to create a so called convection flow through the house by low and high placed window openings. The hot air rises to the ceiling and is released through the high window being replaced by cooler air from the lower window. Windows and doors can also be placed to utilise a cross flow through the house to get fresh air in. Both exhaust fans and ceiling fans are additional types of controlled ventilation which are good for passive houses due to their high energy efficiency (SEAV 2002).

4.2.8 Energy Efficiency Appliances

In addition to all building features for an energy efficient home, it is vital to utilise energy efficient appliances to maximise energy savings. Appliances to be considered are efficient lighting such as compact fluorescent lights, energy efficient washing machines, dishwashers and clothes dryers. Additionally, the most energy efficient models of gas space heaters, ducted heaters, air conditioners, refrigerators and freezers should be used (SEAV 2002).

Many of the above mentioned appliances carry Energy Rating labels in Australia, which are important to consider when choosing suitable appliances for the building. The rating varies between one and six stars where more stars indicate a more efficient appliance. There are also Galaxy Energy Award winning appliances which are given to the most energy efficient appliance of each year (SEAV 2002). Internationally similar rating systems exist for efficient appliances.

It is important to stress that such implementations may be more expensive in the installation phase, but that the appliances should be viewed from a life time cost since they do reduce the energy use of the building significantly.

4.2.9 Energy Rated Buildings in Australia

There is a wide range of energy rating tools used in Australia. In most states today the requirement is to get a rating from an accredited assessor who does the calculations and returns the rating for the specific building. There are both different rating systems as well as a mix of approved tools (often software tools) available for the evaluation of a buildings energy performance. Some tools apply for the commercial sector whereas others are used for domestic buildings.

New South Wales uses an energy rating tool called the Building Sustainability Index (BASIX) which is based on three main sections including water, energy and thermal performance. A certificate printed from BASIX is required as part of the documentation provided when applying for building approval (House Energy Rating 2008).

The South Australian Government requires all new buildings to comply with the 5 star energy efficiency required by the BCA. For domestic buildings, approved tools are FirstRate or AccuRate. For a building to pass the council, it either has to have a 5 star rating from one of those tools or be able to demonstrate fulfilment of the BCA conditions (House Energy Rating 2008).

The Western Australian Government only requires a 4 star energy efficiency rating, also using the FirstRate tool as evaluator. This is quite similar to Queensland and Tasmania, which require a 4 star rating where FirstRate and NatHERS are accepted by both, but Tasmania also acknowledge the AccuRate tool. However, it is likely that Queensland will upgrade to 5 star rating within 2009. Also the Northern Territory relies on the FirstRate and AccuRate tools, but only requiring 3.5 star rating. Similarly to other states or territories, an up-grade of the star rating is to expect. ACT requires a submission of an Energy Efficiency Rating (EER) Statement demonstrating the building meets 5 star energy efficiency requirements. However, for building permits, the requirement varies between 4 and 5 star energy performance due to the type of building proposed (House Energy Rating 2008).

All the tools used in Victoria apply under the Victorian '5 Star Standard', which requires a plan for new residential buildings to achieve a 5 star rating from one of the approved tools FirstRate, BERS Pro or AccuRate. Another tool, which is beginning to get attention in councils around Melbourne, is STEPS. It goes beyond the energy rating, including other environmental areas such as water, materials and peak demand. All the states have different concessions on energy efficient related implementations such as insulation, solar hot water installations and installation of rain water tanks. These vary quite frequently and have to be considered at the time of each implementation.

There is also a range of tools for non-residential buildings. The most widely used is GreenStar, which is developed by Green Building Council of Australia (GBCA) and is a voluntary tool which is becoming increasingly popular. Similarly to STEPS it also goes beyond the energy rating to asses many other sustainability categories. Another tool for non-residential buildings is the Australian Building Greenhouse Rating, which not only gives a rating to a building plan, but also monitors the buildings to ensure they are performing at the levels of efficiency expected (Strempel 2009).

4.2.10 Passive design in Zero Emission Developments

The concept of passive design is extremely important in a zero emission development. All the included passive design parameters should be considered in the initial phase of development to ensure the area operates in the most efficient way. If both energy smart appliances and passive design are used, household energy use can be reduced by 60-70% (SEAV 2002) which will obviously decrease the total energy demand and hence the need for energy output from renewable energy and energy efficient technologies. Additionally, it will reduce the need for offsetting actually produced emissions.

Only within Australia, there is an enormous amount of different energy ratings and tools available. Each individual development has to consider which tools to use depending on the location of the implementation. Similarly, both rebates and discounts are available on a location basis. However, it is important to aim for better ratings than those generally required for housing developments, when implementing a zero emission development. The legislated energy ratings should only operate as a base line for the development, where the aim is to be more efficient than required by law, possibly using some of the more developed and complex models.

4.3 Solar Energy

Energy from the sun can be harnessed and utilised both to generate electricity (photovoltaic) and heat (solar thermal). Radiation from the sun will vary throughout the year and with location. Based on the earth's tilt and the location compared to the sun the radiation will vary seasonally, with the radiation in winter being less intense. This is a result of the angle that the rays hit the surface of the earth and can be avoided through placing the solar panels on an angle appropriate to the specific location on the earth.

However, winter will still provide lower outcomes due to less sunlight hours. A higher dispersion of the solar rays will also occur since the solar rays enter the atmosphere on a greater angle and hence travel a further distance through the atmosphere. The conditions for using solar energy are fairly good in Australia, and solar electricity or solar thermal energy can be generated in any state or territory. Suitable use of solar energy in zero emission developments are solar PV for electricity production, solar thermal for hot water heating, additional heating and cooling and on a larger scale in solar thermal power plants.

4.3.1 Photovoltaic (PV)

Technology

Solar photovoltaic panels convert energy in form of light from the sun into electrical energy. The efficiency of PV cells is generally between 4-22% depending on the type of panels and also the conditions under which it is operating (ATA 2004). Photovoltaic systems convert energy from the sun into electricity through semi- conductor cells which are arranged in solar panels. The panels are connected to an inverter to turn their direct current (DC) into 240 volt alternating current (AC) for use in dwellings, industries or to export it to the national electricity grid (Maunsell 2004; Brown, Noble et al. 2009). The size of a photovoltaic cell is expressed in kilowatt peak (kW_p) potential, indicating what the system could generate at optimum conditions (Maunsell 2004). However, electricity is measured in kWh (kilowatt hours), i.e. using 1 kW for 1 hour results in 1 kWh consumed. To determine the average output of a panel, the location also has to be considered. The table below shows the average kilowatt hours of energy which can be produced in one day in some major cities in Australia, using a one kilowatt (1 kW_p) solar PV system.

Table 2: kWh produced in Australia from 1 kW_p PV system (Shone, Stapleton et al. 2008)

City	kWh per day
Melbourne	3.15
Sydney	3.50
Adelaide	3.74
Brisbane	3.74
Cairns	3.81
Perth	3.94
Alice Springs	4.46

There are three different types of solar electricity systems: Remote Areas Power Supply (RAPS); grid-interactive systems; and a combination of those two systems. The RAPS and the combination system include large storage batteries. The two grid connected systems will however be the most feasible for zero net emission developments in brownfield, urban infill or precinct areas, and probably also for a greenfield area. A grid connected system allows the dwellings and office spaces to make use of the electricity, with any excess being fed into the grid. Similarly, when the panels are not generating enough electricity the grid can supply the dwellings with power (ATA 2004).

There are three types of photovoltaic solar panels available: *monocrystaline; polycrystalline;* and *amorphous*. The amorphous silicon cells are less efficient than the other two types, however, the production method is less costly making them cheaper to invest in (ATA 2004; Maunsell 2004). The amorphous cells also generally have a lower embodied energy.

Feasibility Issues and Constraints

Photovoltaic panels require only daylight, not sunlight to generate electricity and hence energy can still be produced in cloudy or over cast conditions, enabling them to operate in most areas of the world. The actual performance of the panels depends more on location, orientation and the whole system design than it does on the one cell type used. However, the system should be in locations which are unshaded at all times (Maunsell 2004). The implementation of PV cells on a new building may be easier due to the importance of the orientation and location. Since some panels are quite heavy, it is also possible to ensure that the structure can hold the load if being part of a newly built building.

The grid-interactive system is obviously more feasible in areas with good access to the grid, such as for example brownfields, urban infills, greenfields or developments in precincts. A combination system should be implemented in areas where the grid may not be as reliable and then the battery backup is necessary.

Depending on where in the world the panels are located, the angle and direction will differ. According to the Australian Solar Radiation Data handbook, the amount of solar irradiation in summer is similar falling on a horizontal surface compared to one which is sloped. However, since the solar radiation hits the earth's surface on an increased angle from the perpendicular during winter, the panels need to be sloped for maximum intensity of radiation and hence maximum output. (Brown, Noble et al. 2009). In some parts of the world, the panels generally need to be sloped at all times throughout the year.

Costs and Benefits

Solar PV systems are generally quite expensive to install. However, as interest has grown due to rising environmental issues and newly developed technology, prices are going down. Apart from producing clean electricity the panels have other attractive attributes such as reducing peak load demand. PV systems produce power from mid-morning to mid-afternoon; this is particularly suitable in Australia since that is when peak demands are generally high.

PV panels have no moving parts and are almost maintenance free, resulting in less maintenance costs, which may even out, or at least reduce, a higher investment cost. Cleaning of the panels is normally the most important maintenance since it has a high impact on the electricity produced. By monitoring the average output, it can be determined when the output is much lower than expected, and cleaning is probably required (Maunsell 2004).

The cost of panels varies a lot and it is hard to determine one standard price to rely on. In general, it is found that larger or higher wattage panels provide better value for money, i.e. providing more watts per dollar spent. Price is expected to fall as mass production increases and better developed PV technology is advancing (ATA 2004).

The efficiency of the PV panel can also be increased through installation that provides cooling for the panel. Higher efficiency results in larger electricity outputs and more value for the money.

Tariffs and rebates are also important parts of the implementation of solar PV. Every country or state has different financial compensation systems which have to be investigated prior to construction. In Victoria, Australia, a premium solar feed-in tariff was slated to commence in 2009. It operates on a net basis, meaning that it enables households with a PV system up to 2 kW to get paid for their excess electricity which is fed back into the grid. For every kWh exported, 60 cents is paid to the household (Brown, Noble et al. 2009). The limit to which the system receive feed in tariff differs all over Australia with proposals between a 2 kW limit to unlimited. Moreover, there are also states operating on a gross tariff, where the investor gets paid for the total amount of electricity produced. In terms of zero emission developments, such limitations obviously restrict the possibility to investment in solar PV. For example a gross feed in tariff has really pushed the solar PV development in Germany. A good governmental rebate is a vital part for the future of PV cells to become an important contribution to any countries renewable energy technology.

Small scale PV systems are eligible for rebates and financial compensation under the so called Solar Homes and Communities Plan (SHCP) (Maunsell 2004). Moreover, the earlier discussed RECs may decreases the installation cost.

4.3.2 Solar Thermal

Solar thermal energy is based on collecting the heat generated from the sun through solar collectors. The solar collector can be seen as a type of heat exchanger which transfers solar radiant energy to heat. It generally consists of a well insulated box, a dark absorption plate and a glazing. There are three main types of solar collectors: *Flat Plate Collectors (FPC); Evacuated Tube Collectors;* and *Concentrating Collectors (CC).* FPC are the most common type used and are generally used for temperatures up to 100˚C. It is mechanically simpler than the other types since it does not track the sun. The simplicity of the model makes it low in maintenance requirement. They are generally used for solar hot water heaters. Evacuated tube collectors utilises vacuum for its heat transfer and is generally used between temperatures of 80-180˚C. Those collectors have less heat loss and are hence more efficient. Concentrating collectors also operate at temperatures higher than those of the flat plate collectors. The collectors only utilise the beam radiation and move to constantly track the sun, requiring more maintenance than earlier discussed collectors. Concentrating collectors are generally used in solar thermal power plants. In zero emission developments today, solar collectors are generally used for hot water heaters and additional heating and cooling. However, there is room for discussion to implement solar thermal power plants in such a development, depending on the size of the project.

4.3.3 Solar Hot Water Systems

Technology

As mentioned, solar hot water heaters use both FPC and evacuated tube collectors (Maunsell 2004). The hot water heaters have four main components: the collector panels; a storage tank; gas or electricity boosting; and a freeze protection (ATA 2001). Some systems rely on the thermo-siphon effect. Thermo-siphon means that the warmer the fluid is, the lower the density is, and therefore it naturally rises. Placing the tanks on the top of the roof for these kinds of systems means that the hot water will automatically rise in the pipes and in to the tank (ATA 2001). In some cases due to different reasons, it may not be possible to place the tanks on the roof, and pumps are then required to transport the hot water to the tank.

There are two existing types of hot water heaters: storage hot water heaters; and instantaneous hot water heaters. The storage water heater keeps a tank full of water ready to use when required. They are available as either mains pressure or constant pressure hot water heaters. Mains pressure solar hot water heater allows a stronger flow. The constant pressure is also referred to as gravity feed, which applies when the tank is open vented to the atmosphere. Instead the pressure is held by the height of the so called header tank (not the supplier tank) (ATA 2001).

There are generally three main types of hot water heating: *close-coupled mains pressure solar water heater; gravity feed solar hot water system;* and *split system* (ATA 2001). The close-coupled system is the most commonly used system. The tank is fixed immediately above the collector panels, and the thermo-siphon effect is utilised. Those systems operate mains pressure. The gravity feed system has the tank installed inside the roof so that only the panels are seen from the outside, also depending on thermo-siphon circulation. If desired, both those systems can operate with pumps as well. Lastly, the split system is implemented when it is impossible or disliked to place the tank on the roof (ATA 2001).

Feasibility Issues and Constraints

Choosing the right system for the right location is an important step in the implementation process. For example, mains pressure solar water heaters are suitable when water is supplied from the reticulated town supply or a pressure pump. In comparison the constant pressure system will generally last longer since it is not under any pressure. It is also normally cheaper to buy but more expensive to install (ATA 2001).

Similarly, differences exist between the storage and the instantaneous systems. With the instantaneous water heaters the water gets heated as required, thus it does not need a large storage tank. Hence instantaneous heaters take up less space and they cannot run out of hot water since it is instantly supplied.

The required placement of the tank also impacts the decision of the most suitable system. Advantages with the split system are having the tank, thermostat and different valves at ground level for replacement. However, the pump in the system draws electricity, which is not required by the other two systems (ATA 2001).

All the above comparisons show only a small part of the evaluation process required. The most feasible system has to be considered for each particular location. There is however many different combinations to choose from and most areas and parts of the world should be able to utilise solar hot water heating as an individual investment or as part of a zero emission development or similar project.

Costs and Benefits

In general, evacuated tube collectors are more expensive, but producers claim better winter performance (Maunsell 2004). Such costs need to be evaluated based on the winter performance at the specific location of the implementation of the development.

Solar hot water heaters tend to be especially beneficial for homes or buildings where hot water is utilised throughout the day rather than at night time. Such places could be service homes for elderly, day care centres or family homes with small children (Maunsell 2004)

Government rebates in Australia continues to vary with time. However, the incentives have at times made quite an important difference to the investment cost and should definitely be investigated before implementing a system. Solar hot water systems also fall under the MRET scheme earlier discussed. But a different RECs system is used based on the type of hot water system installed (Brown, Noble et al. 2009).

The sun does not supply enough heat at all times throughout the year and the systems require some kind of additional boosting system. Such additional heat generally comes from electricity or gas (ATA 2001). If the aim is to create a zero emission development, gas boosted system may be better if electricity is produced off site and imported. In such situations, the gas boosted systems create less greenhouse gases to offset. One solution could be to use on site produced electricity or heat energy from renewable energy sources or energy efficient technologies, eliminating the need for a boosting system.

4.3.4 Solar Heating and Cooling

Technology

Both flat plate collectors and evacuated tube collectors may be installed as additional heaters to a system, which is the case at Bo01 in Malmö (see case study 3).

In terms of cooling, solar thermal energy may be used in a thermally driven cooling process (Brown, Noble et al. 2009). There are two main techniques which allow for solar thermal collectors to function as cooling systems; *closed systems (chilled water systems)* and *open systems (air cooling systems)* (Konrad 2006). The thermally driven chilled water systems produce chilled water to use for any kind of air-conditioning, whereas the open cycle system treat air to provide it at comfortably cool temperatures (Henning 2007). The closed system operates under three temperature levels: a high temperature level at which the driving heat is generated; a low temperature for generation of cooling; and a medium temperature that dissipates heat to the environment. The solar heat from the collectors provides heat to the high temperature level. In the open systems, dehumidification is performed on the air which will later be supplied to cool a room or building. Such dehumidification is performed by a desiccant rotor, and the driving heat for the rotor is supplied by the solar collectors (Konrad 2006).

Feasibility Issues and Constraints

The use of solar cooling today is still quite marginal. The chilled water systems that are commercially available are generally above 35 kW, and hence installation requires an industrial process or similar (Konrad 2006). Moreover, no standard guidelines exist and there is a lack of information of common practice for both design and operation (Henning 2007). Due to these facts, the feasibility for zero emission developments is limited. Nevertheless, if any small industrial processes are to be considered within the development, solar cooling may be an option. In addition, solar cooling might be of value for larger supermarkets, within the development, where the cooling demand is high.

Costs and Benefits

Since solar cooling still is in a research and development state, and especially when it comes to residential applications, the installation will be expensive in comparison. In terms of new development, it is paramount that the planning process takes into consideration passive cooling techniques to limit the need for active cooling systems as much as possible.

Using solar thermal energy for cooling is beneficial due to the match between peak demand of cooling and solar thermal output. Importantly, the push for further development within the area is strong, which will eventually benefit projects such as zero emission developments. This may be especially important in countries where the demand for cooling is big, such as large parts of Australia.

4.4 Wind Energy

4.4.1 Technology

A regular wind turbine generally consists of a main tower, the rotor blades which are attached by the hub, the nacelle which holds the gearbox, an electrical generator, a yaw mechanism, a hydraulic system and a cooling unit along with the anemometer which measures the wind speed and fluctuations (DWIA 2003a). The power generated is available in the kinetic energy of the mass of the moving wind. The kinetic energy passing through the blades is converted to mechanical energy rotating the blades. The blades are connected to a generator and electricity is produced (Ahilan 2009). The power output from the wind turbine is dependent on the swept area of the rotor blades, the wind speed and the density of the air. However, the wind speed is the predominant factor. As the wind speed increases, the power increases with a power of three (Ahilan 2009). The relationship between the wind speed and the power output is demonstrated in the graph below:

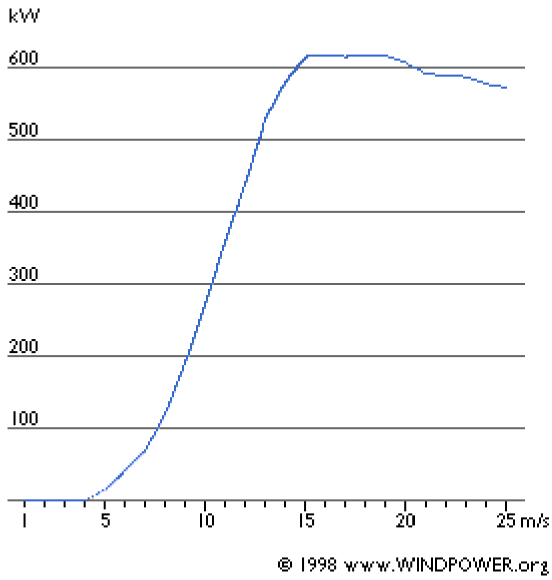

Figure 4: Relationship between wind energy output and wind speed (DWIA 2003b)

As shown, the increased wind speed has a great effect on the electricity generated. The actual power output also depends on several other factors such as type of machine and rotor blades used and friction losses. In reality about 30-45% of the power in the wind is extracted (Ahilan 2009). Hence every turbine has a coefficient of performance estimated for real power output calculations.

Turbines are generally built to make use of wind speeds between 3-30 m/s (Brown, Noble et al. 2009). Small wind turbines, intended for small businesses or residential buildings must have a rotor diameter of 8 m or less. They are generally mounted on towers smaller than 40 meters, but can be as small as 3.5 meters high. Larger scale wind turbines can have rotor diameters between 50 and 90 meters, placed on towers at the same height. Wind turbines being manufactured today range between an output of 250

W to 5 MW (AWEA 2009). However, the output stated on the turbines refers to the maximum produced power, and are rarely reached in reality, hence the earlier discussed coefficient of performance.

4.4.2 Feasibility Issues and Constraints

The dependency on wind conditions is always a returning issue when discussing the installation of wind turbines. Firstly, profound measurements of both wind speed and fluctuations have to be carried out at the specific location of the implementation. Especially long term weather changes may affect the power output from the turbine.

The perception of wind turbines in the landscape is an issue that the industry has had to deal with. Such perception is to a large extent matter of taste and how the turbines historically is perceived as something unnatural which does not fit into the landscape. To change such perceptions, the turbines have to be promoted as part of the nature, actually increasing the possibilities for a future sustainable environment. In terms of sustainable projects such as zero emission developments, such issues should not be exceptionally hard to overcome since the wind turbines naturally promote the purpose of the project, highly visible on the site.

4.4.3 Costs and Benefits

The wind turbine technology has developed significantly during the last 15 years, reducing costs and allaying some assumptions of wind being unreliable. Wind energy could definitely be a significant part of the electricity production in a zero emission development. As mentioned, it is quite location specific, but countries all over the world, with very different weather conditions find ways to utilise wind energy. Since it exists in such a wide range of electricity outputs, developments at different levels are able to utilise wind as a renewable energy source. It can be as a small installation powering on site electric cars or specific iconic buildings or it can be the main electricity supply to the development, all depending on preference of choice and location conditions.

The cost for a turbine will decrease per kW as the size of the turbine increases. Moving from a 150 kW machine up to 600 kW machine, the price will approximately triple rather than quadruple due to the production costs and manpower required does not differ that much when constructing the different machines (DWIA 2003c). Hence, it is worth considering investing in larger turbines when possible, which may be an opportunity for zero emission developments, where the electricity requirement is normally based on the demand from a combined community within the project. The main incentive used for installation of wind energy in Australia is the creation and selling of RECs.

4.5 Hydroelectric

4.5.1 Technology

Hydroelectric technology is the use of moving water to harness energy. There are a few different ways in which water can be utilised. For example the motion of water moving due to tidal forces can be used to generate electricity. Similarly, the flow in a river can be harnessed for electricity production. However, the most common method is the capture of water in great dams, to be release when electricity is needed (Childress 2008). Turbines are placed in the flow of the water, to produce mechanical energy, which causes turbines to turn. The turbines then drive a generator, which generates electricity. The amount of hydroelectric energy which may be generated is related to the vertical distance, referred to as head, between the turbines and the start of the fall of the water (Maunsell 2004). The dam is constructed over a river, fiord or similar body of water. The water banks up behind the dam, creating a head of potential energy. A passageway is built inside the dam down to the turbines and the generators and when the water is released, the kinetic energy in the water makes the turbines move as the water rushes through them (Childress 2008). The head of water can be only a few meters in smaller systems, up to hundreds of meters in larger schemes (Maunsell 2004).

Hydro is often divided into small and large hydro, where small hydro can be further divided into mini and micro hydro. Micro hydro is defined as less than 100 kW and mini hydro is smaller than 1000 kW (Brown, Noble et al. 2009). Smaller hydro systems would be the most suitable in terms of zero emission developments.

4.5.2 Feasibility Issues and Constraints

The flora and fauna in and around the river is an extremely important issue when constructing a dam. Obviously, a dam has a large impact on the natural, environmental flow of the river, which may have a great impact on fish and other water animals as well as vegetation in and around the waterway. The impact of the dam depends on different factors, size being one of them. A larger dam, generating more electricity generally has a higher environmental impact compared to the small hydro systems (Brown, Noble et al. 2009). A commonly known impact of dams on river systems is the disruption in the spawning cycle of fish, for example salmon. As they migrate upstream to lay their egg, they are hindered by the dam. Solutions to such problems are possible in the way the dam is constructed (Childress 2008).

The implementation of small hydro obviously restricts the choice of location for the development. If a suitable site close to a water system is to be found, the permission to create a small hydro system has to be achieved. To build a dam and divert water through the turbines will require some form of license in most parts of the world. The issue may be even bigger in a country like Australia, where water is scarce and many waterways are already damaged.

4.5.3 Costs and Benefits

Hydroelectric have the benefit that it is possible to control the electricity generation. In countries where it is a major part of the electricity supply it has often acted as stabiliser to match supply with demand at each instant (Holm 2002). Similarly, small hydroelectric power systems could be used to balance the need within a zero emission development. Some of the above discussed renewable energy sources, such as solar and wind, does not have this capability and hence a combination of both could be an option.

The implementation for a small hydro system is as mentioned very site specific and hence only likely to be suitable for some zero emission developments. It is then vital to stress the importance of environmental flows in the river and restrict the implementation to small hydro systems. Since zero emission developments promote the fact of being environmentally aware, environmental issues with local river systems caused by the development itself has to be avoided.

4.6 Co-generation

4.6.1 Technology

Co-generation or Combined Heat and Power (CHP) generation is a technology where both heat and power are produced. It involves simultaneous production of heat and electricity, usually through the use of steam and hot water. CHP systems consist of a number of individual components such as prime mover (for example heat engine), generator, heat recovery and electrical interconnection. The prime mover, which runs the system, is what identifies the CHP. Typical prime movers include reciprocating engines (generally internal combustion engines), combustion or gas turbines, steam turbines, micro turbines and fuel cells. Fuel is burnt in the prime mover producing either shaft power or mechanical power, where the mechanical energy is in most cases used to drive a generator which then produces electricity (EPA and CHP Partnership 2008). The excess heat from electricity production is mainly used for space, water or process heating and electricity is used in dwellings and commercial buildings or exported to the grid (Maunsell 2004). The heat is most commonly distributed through a district heating system.

The greatest advantage with a CHP plant is the increase in efficiency compared to produce heat and electricity individually. A typical efficiency increase is shown below:

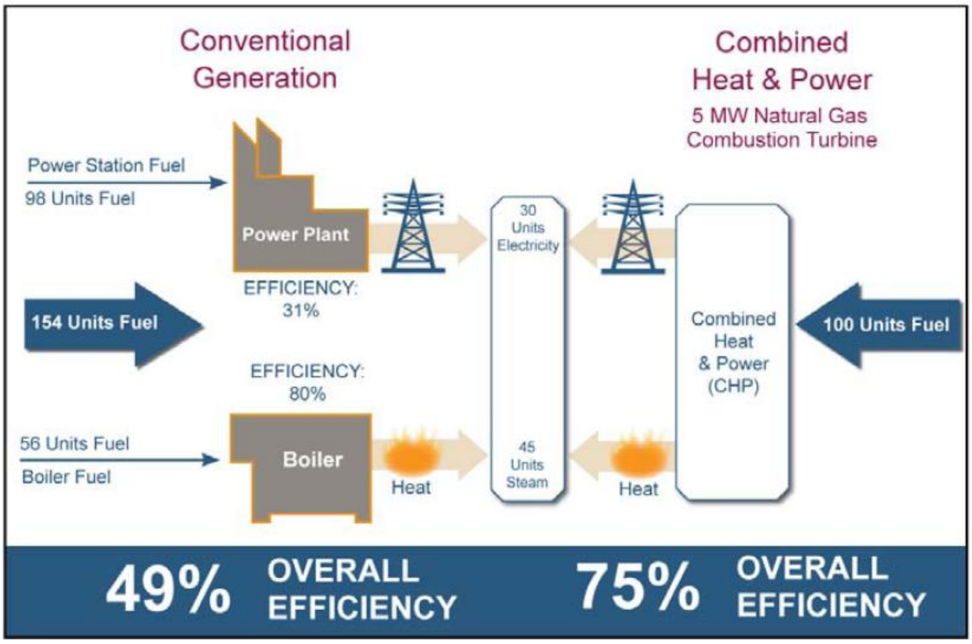

Figure 5: Typical efficiency in Combined Heat and Power plant (EPA and CHP Partnership 2008)

The efficiency of co-generation plants are estimated to be around 75% (EPA and CHP Partnership 2008a). It is important to stress that the efficiency in the literature is quite variable, which may depend on a range of reasons. For example, the heat and power output ratio has an impact on the efficiency, where a higher thermal output generates a higher efficiency (EPA and CHP Partnership 2008). Moreover, different types of prime movers have an impact on the estimated efficiency. However, compared to a conventional approach of producing the same amount of heat and electricity, CHP plants have the potential of using 20-30% less fuel (Andersen and Lund 2007). The technology is mainly suited where the heat and electricity demand is high over long periods. It can be said that co-generation generally produces 2 units of heat to 1 unit of electricity (Brown, Noble et al. 2009).

4.6.2 Available Biomass Fuel

The earlier mentioned prime movers are capable of burning a variety of different fuels, including natural gas, coal, oil, and alternative fuels (EPA and CHP Partnership 2008). When discussing CHP alternatives for zero emission developments, the use of alternative renewable energy sources is a preferable option. Biomass energy is energy from the sun stored in plants and other organic materials. Different biomass options are available as fuel for co-generation and the most suitable option is generally determined by local availability.

Biomass for CHP can be converted into a gaseous fuel through gasification. However, substantial cleaning of the gas is required before it can be reliably used in the engine (Brown, Noble et al. 2009). For example, waste wood or pellets can be utilised, especially if they are available through industries in the local area of construction. An example of such an existing co-generation plant is in the zero emission development BedZED (see case study 1).

Biogas can also be produced through biomass digesters or the use of landfill gas can be investigated. An example of producing on site biogas from residents own food waste is in the zero emission development Bo01 in Malmö (see case study 3). However, the biogas is only used for heating and alternative transportation fuel rather than for co-generation. Landfill gas is another option of biofuel.

4.6.3 Feasibility Issues and Constraints

In terms of fuel biomass is normally considered to be a CO_2 neutral fuel, as the CO_2 that is emitted during the combustion process has recently been absorbed from the atmosphere by the trees or plants. However, the production of biogas will include some additional embodied energy, which may need to be considered. Particularly for zero emission developments, such decision depends closely on what kind of zero emission approach is taken by the developer.

Similarly, there are issues to consider regarding the different types of existing biomass fuels. As mentioned earlier, landfill gas is an optional fuel in CHP plants. It is sometimes argued that landfill gas is less clean than the non-renewable fuel such as natural gas. However, it is important to take into consideration the possible damage from the landfill gas on the environment and climate change if it was not captured and burnt to generate electricity. Generally the landfill gas is burnt and flared into the atmosphere anyway, so to use it as a fuel is more feasible in terms of emissions reduction.

Similarly, the more controlled biogas produced from collected food waste through bio digesters requires energy in its production phase. As for producing biogas from wood, external energy inputs may have to be considered and possibly offset. The use of biogas, rather than for example burning wood, is still a better option in co-generation plants (Maunsell 2004). One of the reasons being the older conventional wood burning method requires a much bigger plant, generally not suitable for developments such as zero emission developments, and especially on a brownfield site, urban infill or within a precinct, where space may be limited.

There are no natural limits on the range of sizes of biomass CHP (Maunsell 2004). However, at present the systems are mainly available for large communal systems, which would suit a wide range of zero emission developments. Furthermore, the systems can be housed in separate buildings, or in the house where it is to serve, only having an external flue for combustion gases, showing the on-site heat and electricity production. Several demonstration and prototype biomass CHP plants do exist but no reliable systems are available at present, resulting in some risks included in the implementation of such technology.

Issues with demonstration plants are discussed in the case study done on BedZED in Beddington (see case study 1). In BedZED, the co-generation plant is not functioning ever since it blew a gasket in 2005. Being one of the first of its kind, developers are still working on a solution to get the co-generation plant up and running again. At Bo01 in Malmö, the attempt was made to produce their own biogas from the residents own food waste. Even though two different food waste collection systems were implemented, there are still big issues with the biogas production today.

4.6.4 Costs and Benefits

Since a simultaneous demand for both heat and electricity is often needed, co-generation can contribute significantly in meeting such demand. The technology is particularly environmentally effective when run on biomass.

Energy efficiency conservation and more efficient use of energy represent a major part of the actions taken towards reducing greenhouse gas emissions. The increase in efficiency gained by introducing co-generation plants is only possible due to the simultaneous production of both electricity and heat. Such savings will have great impact on the cost of fuel. If food waste from a nearby industry is used as fuel, the cost may decrease even more in comparison to conventional fuel.

Even though biomass co-generation is not widely implemented, the technique of actual combined heat and power production is well known. Hence, the area in need for development is the combining of biogas production and co-generation technology. Along with increasing knowledge about the technology, the costs will decrease enabling more developments to consider the alternative. The actual costs of a biomass CHP plant is presently hard to estimate due to the lack of existing operating systems. Instead specific quotes are required as the technologies become available (Maunsell 2004).

Maintenance of the biomass co-generation plant is estimated to be quite high due to the complex technology involved (Maunsell 2004). This obviously involves additional costs, but an onsite heat and electricity generating plant may also produce local jobs and boost the economy in that sense. However, the same complexity is required for all scales of CHP plants which lead to a general trend of reducing installation and operational costs per kWh for increasing size plant.

As most co-generation plants distribute the heat through a well implemented district heating systems, the implementation of the plant need to include such a system. For a zero emission development this can be achieved when the newly built dwellings and commercial buildings are constructed. As long as the co-generation is part of early development plans, the district heating system can be considered. In terms of including existing precinct around the development, it may be slightly more complicated. If there already is an existing system, connections to the new co-generation plant should be possible. Otherwise, expanding the district heating system can definitely be part of extended development plans.

Both CHP and renewable energy are currently important parts of the European climate change policies (Andersen and Lund 2007) and this will hopefully be the case in Australia in the future. It can effectively reduce peak load and energy consumption from the grid both reducing greenhouse gas emissions but also securing electricity for the area in which it operates.

4.7 Tri-generation

4.7.1 Technology

Tri-generation is an extension of the co-generation production. Instead of only producing heat and electricity, tri-generation includes combined production of electricity, heat and cold. This is a relatively recent technology, obviously also leading to increased efficiency compared to separate energy production. Most of the tri-generation plants are based on gas turbines or internal combustion engine cycles, combined with an absorption-type chilling machine for the cooling part (Oztop 2006).

4.7.2 Feasibility Issues and Constraints

Since tri-generation started to develop in the last decade, there are not a great number of plants operating around the world. Hence technical feasibility issues or constraints are difficult to determine at this stage.

4.7.3 Costs and Benefits

Tri-generation is particularly beneficial when thermal demand during winter is accompanied by great cooling demand in summer (Oztop 2006). Such sites could easily be identified in certain parts of Australia.

As discussed earlier, tri-generation is a very recent technology and hence it makes it hard to estimate the costs for an implementation. Similarly to co-generation, savings will probably be possible on fuel due to increased efficiency.

In terms of zero emission developments, particularly in Australia, the implementation of a tri-generation plant could be interesting due to a demonstration value. Since parts of Australia have both strong heating and cooling demand, it should in theory be a suitable investment.

4.8 Heat Pumps

4.8.1 Technology

Heat pump, or refrigerator, is a well established technology which has been used for decades. Common applications of the heat pump are fridges and air conditioning systems. As known form the second law of thermodynamics, heat generally flows from a hotter region to a cooler region (Brear 2008). However, with a relatively small addition of work, a heat pump can reverse such flow and hence be used for both cooling and heating purposes. They use the so called refrigeration cycle. In doing so a fluid, the refrigerant, circulates through the heat pump system, picking up heat from one place and dumping it into another (Begert 2006). The temperature of the refrigerant depends on the pressure it is under where a higher pressure results in increasing temperature. Decreasing the volume of the fluid (compressing it) will increase its pressure and hence temperature. Expanding a fluid will then obviously decrease the temperature. Both compression and expansion of the refrigerant is necessary in the operation of a heat pump.

Heat pumps consist of a compressor, condenser, evaporator, an expansion valve and pumps (Brear 2008). The compressor applies pressure to the refrigerant and the temperature goes up. In the condenser the refrigerant condenses i.e. goes back to liquid form, and heat is released. In the expansion valve the refrigerant is expanded and the temperature drops and when the now cooler refrigerant passes through the evaporator, it evaporates using heat from the surrounding environment. The refrigerant used has to have evaporation and condensation qualities which match the surrounding temperature it operates in.

The basic principles are shown below:

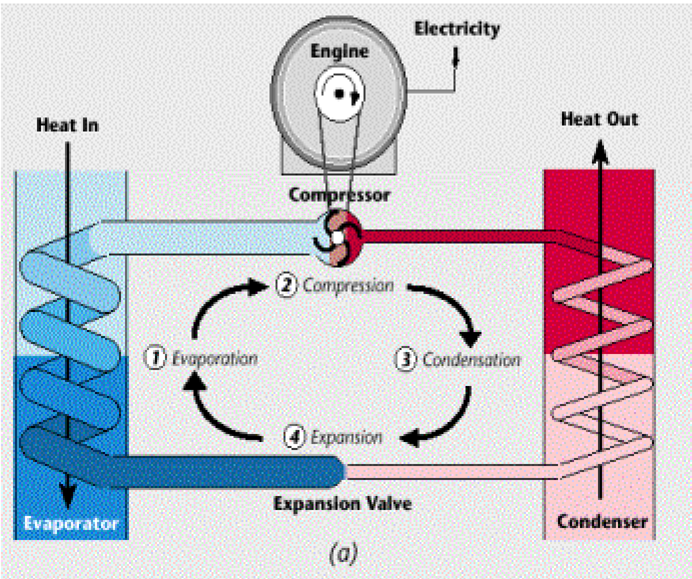

Figure 6: General principles for a compressor heat pump (IEA Heat Pump Centre 2009)

The compression of the refrigerant can be carried out differently. An electricity run compressor can be utilised, which is seen above. The pressure may be applied through an absorption cycle, which can be driven by producing heat from natural gas or biogas. Or through utilising direct solar heat (Begert 2006).

The principles of such heat pump are shown below:

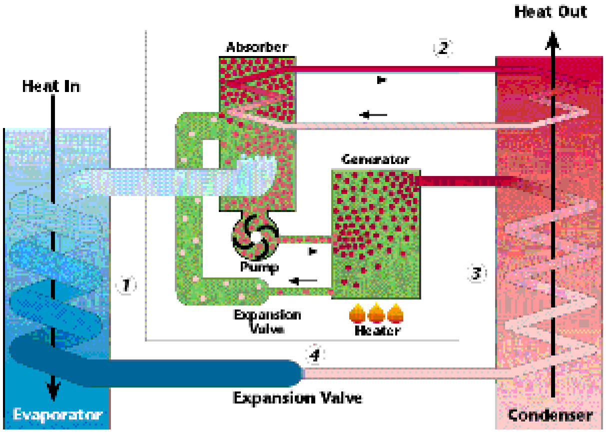

Figure 7: General principles for an absorption heat pump (IEA Heat Pump Centre 2009)

The performance of a heat pump is measured through its Coefficient of Performance (COP), which is based on the ratio between the heating or cooling output to the energy required from the compressor and the pumps. Theoretically the COP for heat pumps used for heating is 1 unit higher than the COP when used for refrigeration (Brear 2008). However, in reality the COP is also dependent on factors such as temperature difference, the performance of the refrigerant (Begert 2006), the heating/cooling load and the heat pump system used (Sanner, Karystas et al. 2003).

There are different heat pump systems available on the market for cooling and heating of houses. The most common type is the air to air heat pump. A more recent technology however, is the ground source heat pump. A ground source heat pump is a regular heat pump system with a heat exchanger buried in the ground, utilising the existing heat or cold. It exists both as a vertical and horizontal system, which refers to the orientation of the heat exchanger (Begert 2006). There are also ground source heat pump systems which are fed by groundwater from groundwater wells (Sanner, Karystas et al. 2003). When used in a cooling mode the earth is used as the sink where heat is dumped (the condenser) and when used in heating mode, the earth operate as the heat source (the evaporator) (Sanner, Karystas et al. 2003). The advantage with using the ground as a heat or cold resource is the temperature consistency which results in a higher COP (Begert 2006). In good ground conditions and with an optimum building heating system, an average COP of 4 may be achieved (Sanner, Karystas et al. 2003). Since the ground source heat pump is more efficient, and also suitable for larger installations, this is the application that should be considered in terms of zero emission developments and hence following discussion solely regards ground source heat pumps.

4.8.2 Feasibility Issues and Constraints

The heat pump is not a renewable energy technology in itself since it does require either electricity or heat energy to operate. However, since they represent a very efficient way of both cooling and heating, the technology could be applied but operating through the use of renewable energy sources. As mentioned, the absorption system requires heating, which may be applied through solar thermal energy or biomass. As for the compressor run systems, electricity could be supplied through wind energy or solar PV. A decision on which technology is most suitable has to be made based on available renewable energy sources within the development and the COP of the heat pump based on temperature conditions at the specific location.

The horizontal system is a network which is buried at around 2 meters depth in the ground. Being horizontal, it obviously requires a large area, which may be an issue when an implementation is performed in a brownfield area, an urban infill or a precinct. On the contrary, the vertical system requires very little space, reaching down between 15 to 150 meters into the ground (Brown, Noble et al. 2009). However, access for a drilling rig is necessary in the construction phase. If the implementation is a part of the initial construction such drilling should not create an issue.

A detailed ground survey would have to be performed on each particular site. A survey should include ground conditions and underground obstructions such as sewers or tunnels (Brown, Noble et al. 2009). For example, the groundwater surrounding the pipes in certain systems has to be of a quality which will prevent damage to the pipes and the heat pump (Begert 2006).

Heat pumps operate on relatively low temperatures. If they would be to be part of an already existing heating system, the operation temperature may cause a problem. Since many existing heating systems are high temperature systems, the installation in already existing buildings entails a total replacement of the heating system (Sanner, Karystas et al. 2003). Considering zero emission developments, this only applies if the project is to involve a precinct when using a heat pump for heating.

4.8.3 Costs and Benefits

The main cost for the ground source heat pump is the installation of the pipes in the ground. Such costs are dependent on the ground conditions and obviously the length and depths of the system. Moreover, the market penetration is still quite modest throughout Europe (with an exception of Sweden and Switzerland) (Brown, Noble et al. 2009) and the rest of the world, resulting in costs still being fairly high for installation of the systems.

The above discussed ground surveys that has to be done adds costs to the project. Firstly, the actual research may be both costly and time consuming. Also, depending on the area costs can be high due to the formation of the site. It is for example, more expensive to drill through areas of solid rocks, compared to other ground conditions (Brown, Noble et al. 2009).

A heat pump system involves both heating and cooling. That is an advantage when comparing it to heating through cogeneration or with other waste heat, since cooling then has to be considered separately.

4.9 Abatement Strategies- Carbon Offsetting

In the aim to become zero emission as a development, offsetting some of the emissions is an option. An offset is a greenhouse gas emission reduction product making it possible for both individuals and businesses to reduce the emissions they are responsible for. This is done by reducing or displacing greenhouse gas emissions in another place through sequestrating carbon from the atmosphere.

The greenhouse gases in the atmosphere today include a range of different gases. Some of them are water vapour, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, where water vapour is the main natural greenhouse gas. Human activity does however not appear to have directly changed the concentration of water vapour globally. Instead, carbon dioxide is the major discussed greenhouse gas. It takes up a small, but constantly growing part of the atmosphere. All greenhouse gases have different abilities to trap heat and they also exist in the atmosphere for different amounts of time before being removed due to natural processes. Based on that, different gases have different global warming potential (GWP). Carbon offsets are measured in CO_2 equivalent. Such equivalents make it easier to lump together the warming effects of several different gases and are derived from the global warming potential of each gas (Commonwealth of Australia 2008).

Emissions may be offset in different ways. As discussed earlier, excess renewable electricity produced on site may be fed into the national grid to offset electricity used at times when the renewable energy sources have not been sufficient to support the whole development. If as much, or more, electricity than what was initially extracted from the grid is fed back within a certain time period, the development produces zero net emissions of greenhouse gases.

It is not only renewable electricity which may be used as an abatement strategy. Renewable energy, for example heat produced on site, may also be sold and exported to surrounding areas, offsetting emissions produced when non-renewable energy have been imported. This strategy is implemented in the zero emission development Dockside Green in Canada, where the exporting of renewable energy in the form of heat is meant to offset their import of electricity from the grid.

The most popular form of carbon offsetting is through reforestation (EPA 2008). Since trees take up carbon dioxide, new plantation will increase the reduction of CO_2 in the atmosphere and may be used to offset the release of the same amount of CO_2 from in this case the development. Offsetting emissions through tree plantation can be done on any level, from personal offsets to big industries. However, the calculation of how to offset the emissions differs depending on country, state and also individual companies and organisations.

Methane is a greenhouse gas which can also be used as an abatement strategy. It is generally produced through: livestock releasing methane through manure; decomposition of waste stored in the ground, resulting in methane referred to as landfill gas; and as a waste gas in coal mines. Landfill gas can be burnt as a fuel to generate electricity, producing carbon dioxide, instead of being wasted into the atmosphere. Similarly, methane from coal production can be burnt and flared into the atmosphere or burnt as fuel (EPA 2008). Burning methane will still produce carbon dioxide, but using the greenhouse gas to produce energy before releasing it to the environment still enables utilisation of the gas before it is released to the environment. The methane derived from the coal mine will then produce more energy, but releasing the same amount of greenhouse gases.

Energy efficiency can also be used as a carbon offset. The decrease in energy use due to increased efficiency is estimated as a carbon offset compared to earlier released emissions. Energy efficiency as offsets do involve issues such as the accuracy and reliability of baseline measurements and changes in people's energy behaviour over time (EPA 2008).

4.9.1 Australian Emissions and Carbon Offsets

The Australian Government's intention is to commence the Carbon Pollution Reduction Scheme (CPRS) in 2010 (Australian Government 2008a). Such scheme will be the primary tool to drive reduction of greenhouse gas emissions. To do so, a cap will be placed on emissions. Setting a limit or a cap on the total amount of emissions means the right to emit greenhouse gases becomes scarce and scarcity will affect the price of most things related to the emissions. Important for this implementation is that the cap is set to a level where it actually results in an environmental improvement.

One way to deal with the cap and the limited amount of emissions is offsetting any additional emissions by above discussed abatement strategies. However, there is no standard way of calculating emission offsets at present and different systems are used by different organisations and companies.

Different systems in use are especially evident in the reforestation business. Systems can be based on a year-to year basis where the carbon has to sequestered in the same year as it is released. As a result of such system, many trees have to planted initially but those trees can then be reused next year to offset emissions that will be released then. Another way to account for the offsets is via a lifetime sequestration. Such system involves planting trees and then accounting for their lifetime sequestration to offset the emission for that year. This results in fewer trees initially required to be planted. Such system may be unreliable due to the fact that it is hard to foresee what will happen to the tree and if it will sequestrate all the carbon dioxide as calculated. The CPRS will not allow lifetime sequestration but encourage the year-to year method (Richardson 2009).

The above example is only one of many showing the complexity of the carbon offset market and the need for a well implemented offset system, to accurately account for the emissions sequestrated.

4.9.2 Offsets for Zero Emission Developments

There are several options for carbon offsetting for zero emission developments. It can however be discussed how much the developments emissions that should be offset. Depending on what the goals are for each individual development, the opportunities for offsetting are limited. For example, some zero emission developments have goals on a certain amount of renewable energy production on site. In particular, when acting as a demonstration to other communities, cities, states or countries, the importance of creating local renewable energy rather than offsetting could be of paramount importance.

A viable option of offsetting within a zero emission development is the feeding excess renewable electricity into the grid to offset for times when the renewable energy sources are scarce. Then the development is still self sufficient in terms of electricity over a certain time period.

As energy efficiency is a part of offsetting emissions, this could be utilised in zero emission developments. However, it is most likely that such offsets would only apply to retrofitting of older dwellings and buildings if the project was set out as part of a precinct.

If a co-generation plant is part of the renewable energy installations, landfill gas has been mentioned as an optional fuel. Since landfill gas can be used as an offset when burnt as a fuel, it could be a beneficial option for zero emission developments. However, the issue of the landfill gas still emitting greenhouse gases can be something hindering the project developers from this option.

Reforestation is obviously also an option to offset any emissions the development may be forced to emit due to non-renewable energy use. If the area is carbon neutral in itself, and does not need to offset emissions as it is operating, reforestation may be a good alternative in terms of being zero emission from an energy building perspective.

4.10 Retro-Fit of Old Buildings

Many existing homes today are built without any or little concern of the environment. However, there are a range of retrofitting actions to be taken to improve both the comfort for those living in the house and its environmental performance. Retrofitting of homes can be done on different levels, and over a period of time. It can be started off as small behavioural changes and implementations, increasingly adapting new retrofitting actions. The attitude of people involved in these types of implementations is vital for a noticeable change to occur. Retrofitting homes in a zero emission development will be particularly important if it is part of a precinct. Lowering the emissions of existing homes will simplify the process of becoming a zero net emitter as a whole. Below is a range of adoptions which can be made to create a more energy efficient home. Many implementations go along the same lines as passive design.

4.10.1 Environmental Awareness

The environmental awareness of people living in homes being or to be retrofitted is vital for optimum outcome. As part of the environmental improvement the residents should try to reduce their emissions by making smaller changes. It is of critical importance those residents are informed about how to behave within their household to minimise energy use, but still live comfortably. There are simple actions, when they are known, which can be taken to make a difference. Such changes can be taught and implemented as the plan for further retrofitting is being developed to introduce sustainable living.

4.10.2 Behavioural Changes

There are a wide range of changes which each individual can make within a household to create a more efficiently used home. Actions vary in terms of simplicity and it is important that residents are informed about the actions that are required in their homes.

Behavioural changes may include;

- ✓ Being aware of how to reduce water usage through: taking shorter showers; washing full machines of clothing; and full dishwashers.
- ✓ Turning of appliances at power points when not in use.
- ✓ Setting thermostats of refrigerators, freezers and indoor heating to appropriate temperatures. Decreasing or increasing by only a couple of degrees can have a big impact on the electricity use.
- ✓ Being aware of ventilating air through the windows after sundown, but closing up later at night to conserve the heat.
- ✓ Using proper gardening and the right type of vegetation to provide shading in summer, still allowing for the winter sun to come through.
- ✓ Knowing which appliances in your kitchen are most suitable for energy efficient use. For example, oven use should be minimised and water should be boiled in a kettle for less energy use
  (Moreland Energy Foundation 2003)

Behavioural changes are often more important than realised. It has been shown that behaviour affects residential energy use to the same extent as more efficient equipment and appliances. Also, household behaviour may vary to such an extent that residential energy use differs by a factor of two, even when the equipment and appliances are identical (Lindén, Carlsson-Kanyama et al. 2006). Other studies show that within the same buildings with the same installations, energy consumption can be reduced by 37% due to more energy efficient behaviour (Desmedt, Vekemans et al. 2009). Hence influencing and educating people to behave more energy efficient is a vital part of both retrofitting and in efficient building design in general.

Issues involving motivating people to change their behaviour can be identified. Lacks of knowledge or motivation for energy conservation are examples (Steg 2008). Knowledge of the importance of reducing emissions does not always transfer into the knowledge of what can be done. People often know little about which energy use is connected to their behaviour. Unfortunately behaviour is also based on a motivation as for example costs. People are far more likely to carry out pro- environment activities such as recycling, which has a low cost in money and effort, than others such as reducing car use which have higher financial and lifestyle costs (Steg 2008).

It is reported that significant savings can be made through providing information about saving previous to the energy consumption of people. For example putting up signs in common buildings to switch lights of or sending a documentary on TV about energy efficiency and possible actions both can provide remarkable differences in energy consumption in a building or area (Wood and Newborough 2003). However, the risks for fallback in such situations should be considered meaning changes often occur initially, due to recently achieved information but tend to reduce in effectiveness after a while (Wood and Newborough 2003).

Another way to provide information is through feedback on energy using and saving techniques. This can be done through individual metering in dwellings and even public buildings. Wood and Newborough (2003) have found three main functions of feedback involving learning function, habit formation and the fact that new habits impose people to create new attitudes to suit the new behaviour. This also goes along the line with motivating people to change their behaviour. In the case of motivation it is important to stress normative and environmental concerns. They are important in promoting energy conservation, because they provide the most solid basis for it. If people only conserve energy for cost reasons, they will stop doing so as soon as the behaviour is no longer attractive or cost- effective. When energy conservation results from normative concerns, it is more robust against such changes (Steg 2008). Generally humans are creatures of habit so if simple actions are relearned, they can be sustained forever

4.10.3 Heating

Heating is a major energy consumer in many Australian homes. In the cooler climate zones such as around Victoria, heating takes up about 30% of the household energy usage (Moreland Energy Foundation 2003). To decrease the need for heating, and to make additional heating more efficient a few action can be taken:

- ✓ Maximise the use of the winter sun, by letting the sun through during the day and closing the curtains at night to save the heat.

- ✓ Draught proof the house by sealing building gaps, windows and doors. Draught proofing is particularly important in heated rooms. Thick curtains or double windows can also be installed to reduce heat loss in winter.
- ✓ Make sure the house is well insulated, with the suitable insulation for the particular house.
- ✓ If the existing heater is to be replaced, high energy rating gas space heating or heat pump should be the option. Within a zero emission developments, connection to possible district heating net should be considered.

4.10.4 Cooling

Cooling is another area which can generally be improved in terms of energy efficiency. Improvement can be made by:

- ✓ Utilising passive cooling as much as possible both through covering windows to block the heat out and to ventilate at appropriate times.
- ✓ Install shading over windows where it is needed. Similar shading devices as described for passive design of houses can be used.
- ✓ The energy use of portable and ceiling fans are a lot less than that of air conditioners, hence the use of those should be maximised before using the air conditioner (Moreland Energy Foundation 2003)
- ✓ If installing new cooling systems, evaporating cooling systems are more efficient (Moreland Energy Foundation 2003). However, in a larger development utilisation of ground source heat pumps may be feasible.

4.10.5 Water

Water use, and particularly hot water use, takes up a big part of household energy use (Moreland Energy Foundation 2003). It is used all throughout the household for clothes washing, dishes and showers. In Australia especially, due to drought conditions, water efficiency is important both in terms of decreased energy and water use. Possible improvements are:

- ✓ Changing to water efficient shower heads and taps.
- ✓ Any other water using devices such as dishwasher and washing machines should be high star energy rated.
- ✓ There are great solar hot water heating systems (see chapter 4.3.3 Solar hot water systems) which can be installed to additionally reduce the energy needed for hot water heating.

Becoming more water efficient, as well as discussed earlier, energy efficient also lies in the responsibility of the resident. Only so much can be done by installing energy efficient appliances. Residents also need to pay attention to how water is used within the dwelling. Great amounts of water can be saved through taking slightly shorter showers, only running dishwashers or washing machines when they are full, scraping plates instead of rinsing before putting them in the dishwasher and use the cold water options when washing clothes.

4.10.6 Lighting

Lighting is another area where sufficient energy savings can be made. Typical installations are:

- ✓ Maximising the use of natural light.
- ✓ Minimise the lighting in rooms that are not being used. Make sure lights are turned off when leaving the room. In larger implementations such as commercial buildings timers or sensors can be used which will ensure lights are only on in rooms that are used.
- ✓ Replace incandescent light globes with more efficient compact fluorescent globes or tubes (Moreland Energy Foundation 2003).

4.10.7 An energy efficient home

In summary, an energy efficient home includes;

- ✓ Efficient heating and cooling equipment.
- ✓ Well insulated floors, walls and ceilings.
- ✓ Draught proofed windows, doors and building gaps.
- ✓ The use of energy efficient appliances such as refrigerators, freezers, washing machines and dryers.
- ✓ The use of natural light and efficient lighting appliances.
- ✓ Water efficient taps and shower heads.
- ✓ Solar hot water systems and solar power.

4.10.8 Retrofitting in Zero Emission Developments

Retrofitting old homes and buildings as part of a zero emission development would obviously occur if the implementation was part of a precinct. The retrofitting of homes in the precinct has some important advantages. Firstly it enables a larger area to work for sustainability and a zero net increase in emissions. Secondly, since some emissions from the old homes are decreased the new development has a slightly smaller pressure on its emission cap.

The emission reduction for the older buildings may allow for more emissions from the new buildings since the goal is to be overall neutral compared to prior to the whole implementation. However, it may be argued that such an approach is not sustainable and the precinct is only used to enable the new dwellings to the use of some non-renewable energy. An option could be to still aim for a zero net emission for the new dwellings and buildings, but to offset some of the building energy required for the new part of the precinct.

Retrofitting also demonstrates how everyone can become environmentally aware and more energy efficient without living in a highly technological newly developed area. In such cases, the importance of efforts to influence and help people to change their behaviour is vital.

When considering the implementation of zero emission developments all these renewable energy and energy efficient technologies, along with passively designed homes and energy management in existing buildings, are vital. However, it is also important to consider the development form a perspective involving social, economic and environmental sustainability as well as considering national policies and the value of evaluation. These factors are discussed in the following chapter.

5 Successful Strategies

Many strategies involving the reduction of greenhouse gases often promote technical solutions and market-based measures like economic and legislative instruments (Horne, Bates et al. 2007). Such strategies are effective to a certain extent, but they are limited in producing motivation amongst the people are to, in this case, live in the new zero emission development. Instead, more resent approaches to different types of sustainability efforts include the importance of understanding the initial behaviour of the individuals and organisations who will be part of, or living in, the zero emission developments, also including economic sustainability with an environmental attitude. An integrated strategy involving more extended approach helps in realising the ultimate implementation required and engages people to actively work for a successful outcome.

It is paramount to realise that sustainability involves social, economic and environmental dimensions and the interrelationship between these has to be acknowledged (McLoughlin and Young 2005). Such integrated approach is vital also in zero emission developments. This is apparent in the three case studies carried out (see chapter 7), where both social and cultural along with economic sustainability is well implemented through different integrated strategies.

Below, the importance of social and cultural awareness and economic sustainability when achieving environmental goals, particularly through establishing zero emission developments, will be discussed. Moreover, additional concerns involving policy context and the importance of evaluation will be explored.

5.1 Social and Cultural Awareness

Human behaviour is complex. However, in order to understand and solve environmental problems it is of great importance to understand their social dimensions. The complexity of human social systems, values and behaviours impacts the struggle to change social structures or enforce sustainable behaviour. This is also parallel to complex and unpredictable ecosystems, and how they respond to sustainability changes (McLoughlin and Young 2005). These two issues of complexity highlights the extent of research required to properly involve social aspects into environmental development.

McLoughlin and Young (2005) argues in '*The role of Social Research in Effective Social Change Programs*' that social research and evaluation is critical to understanding people's interaction with environmental issues, in order to design a program which engages with the views and needs of those part of the implementation. In doing that, the most successful outcome will be reached due to enabling the involved community to easily adapt to the new implementations.

Often this type of research is very problem-specific, and each design is made to a specific place. In terms of zero emission developments, it forces the developers to make some social and cultural considerations early on in the process. This may be particularly difficult since these types of developments often include new people moving in and they do not have a set community to initially work around. Instead, assumptions about people who will be moving in have to be made. Assumptions may be based on surrounding communities, in an attempt to understand their culture. However, expected differences within a new zero emission development can be analysed and linked to comparable developments of similar style.

Areas important to consider when doing social research are the social and cultural structures which exist in the area, which of these can be harnessed and used to positively work for sustainability, what values and interests exists amongst the inhabitants and what socio-economic factors exists (McLoughlin and Young 2005). Again, assumptions will be necessary for zero emission developments but research can also be done based on surrounding cultures and views, particularly if the implementation regards a whole precinct.

After the research stage, a basic knowledge about the existing or future community should be created. With a basic establishment of the social outline of the development, the information is to be used to assist in producing a community that works for the sustainable function of the development. The research will hopefully provide a baseline for how to best inform and influence inhabitants on how to behave, to enable the zero emission development to function.

Another aspect of these types of implementations is to ensure social amenity. If people are comfortable and safe within the community they are more likely to behave in a preferable way to the development. If the development gives something to the people, the people are often prepared to give something back. Important social implementations are the consideration of the inhabitants comfort in their homes and on site, the feeling of safety, community engagement, personal input into decisions and continuously updated knowledge about their community and the site. It is found in the performed case studies on zero emission developments that further social implementations are planned or implemented to create additional benefits for people living on these types of sites. Some of those benefits include local car pools, natural meeting points, community internet and job creation on site.

5.2 Economic Sustainability

The economic sustainability is obviously also vital for zero emission developments to be successful. Costs differ for zero emission developments compared to a regular housing development and hence, the costing approach also has to be different. Economic barriers can sometimes work against a sustainable development (Horne, Bates et al. 2007), but if these barriers are viewed from a long-term perspective, the economic situation might look different. If costs are unusually high for certain things within the new zero emission development it is important to emphasise the cost reductions on other parts of the development, which may come out of those higher costs. The environmental benefits, and hence cost benefits, achieved through zero emission developments should be considered when calculating costs for the implementation. The above discussion highlights the importance of the costing approach taken by the developer. There is evidence that emission neutral developments and their related environmental savings can be achieved to little or even no extra costs compared to standard developments (Horne, Bates et al. 2007).

Initially, the construction of passively designed dwellings may be more expensive, but this does as mentioned result in lower running costs for those homes. High initial costs could also be connected with district heating which is a prominent technology for zero emission developments. District heating requires high maintenance compared to the, in Australia, traditionally used electric heating systems. However, district heating is often needed to reach the zero emission goals for such developments. For the residents, it will often provide heat at a competitive price compared to electric heating (SEA and RENUE 2006).

Split incentives may be an issue in this situation. Split incentive is most often used in the context of building owners not having an incentive to invest in tenancy level energy efficiency, instead it is argued that the building owner would bear the cost whilst the tenant would get the benefit (Garnaut Review Secretariat and Total Environment Centre Inc 2008). This is particularly a problem if the new dwellings in a zero emission development are to be rented out rather than sold. The argument of split incentives can however be questioned. The building owners can recoup expenditure based on the implementation of energy efficient design. Firstly, the tenant's energy use and costs generally reflects the energy use of the base building, which will be higher with an inefficient design, and result in higher costs for the building owners. Also, energy efficient design is still a great marketing opportunity, and the provision of energy efficient tenancies currently offers building owners a competitive edge (Garnaut Review Secretariat and Total Environment Centre Inc 2008).

In terms of selling the new dwellings, the low running costs is an important marketing approach. It is likely that the apartments will be sold for an initially higher price, but those costs can be recovered based on the lower annual costs for the residents.

Costs are allocated differently for every development and particularly for zero emission developments. As seen, higher initial costs can be invested in long term sustainable buildings, resulting in longer life span and lower maintenance costs and also reasonable living costs for the inhabitants (City of Malmö Planning Office 2008). Hence, it is essential to stress the importance of a well implemented costing approach involving possible social and environmental savings. It becomes even more complex when considering the environmental costs involved with not creating a zero emission development. However, it also has to be defined who is responsible for those costs and how they can be accounted for within the development.

Generally, implementing social benefits on a site may increase the development costs. Social benefits can involve earlier mentioned local car pools, meeting points and green areas, communal internet sites, parks, additional bike tracks or other leisure implementations. However, these implementations improve the living standard and also the comfort of people living on site, which will generally result in higher attraction value of the development. A careful balancing act has to be made between higher initial costs and social benefits, to maximise the social benefits without decreasing the profit for the developer to an extent where they might decide to withdraw (SEA and RENUE 2006) The close relationship between environment, economic and social factors is obvious and the need for an integrated approach to overcome these barriers evident.

5.3 Triple Bottom Line

An example of an integrated approach which can be taken by developers is the Triple Bottom Line. This method is used in two of the case studies performed. Realising the complexity of zero emission developments, the triple bottom line interconnects environmental, economic and social objectives.

There are different ways of expressing the triple bottom line. The BedZED development (see case study 1) identifies their sustainability triple bottom line to consist of *Social Amenity, Financial Effectiveness and Reduced Environmental Impacts* (Twinn 2003*)* whereas the Dockside Green (see case study 2) talks about the interaction between *Natural Ecology, Economics and Social Equity* (Dockside Green, Vancity et al. 2007b). Even though the three components use different terminology, both developments strive for the same thing; to consider all factors simultaneously to create a successful development.

Even within the triple bottom line developers are forced to create their own ways of applying the method. This is partly related to the earlier discussed individual focus and research required for each development. However, there are a few significant aspects worth highlighting. One major part is to take away the focus from economic perspective and the belief that the economics determine what can actually be done from a social and environmental perspective. It also aims to show the long term benefits of environmental commitment, such as job creation, improved marketability and energy cost savings (Vancity and Windmill West 2008).

5.4 Policy Context

In order to implement the aims of a zero emission development it is desirable to embed them in as many policies as possible. If this is done, awareness will be increased amongst local organisations and governments, state and federal governments and the public. Also, it will allow for targets to be set and reported against helping to reinforce the aims and objectives of the developer (SEA and RENUE 2006).

The planning framework for zero emission developments are based on a range of policies, including national, regional, local and maybe even site specific policies. National policies are most likely influenced by international commitments made by the country.

The policies are not only divided into the governmental level on which they are developed, but also by the scope of the policy. It is important to consider if the policy applies to all types of zero emission developments, or only selected ones. For example policies could be climate change policies to meet energy targets, general climate change policies and community or urban planning polices (Centre for Sustainable Energy and London Bourough of Merton Planning 2006).

Presently, targets for zero emission developments operate above and beyond existing policy requirements in most countries. Involving those individual targets into more broadly functioning policies, and to raise existing policies to a level at which zero emission developments operate, involves extensive work. However, if such policies are implemented, political support for aims and objectives of the zero emission developments will be gained (SEA and RENUE 2006). The main policies are those for climate change and renewable energy. However, policies can also involve energy efficiency, sustainable design, energy generation, waste, affordable housing and development density. Thus, on local policy levels, more specific targets has to be set, concerning types of onsite renewable energy technologies, implementation timeframes, size of development and particular energy use targets.

5.4.1 Policy in Australia

Since Australia has committed to greenhouse gas limits along with the set Kyoto targets, development and implementation of appropriate policies to achieve large cuts in emissions are required. The need for a range of policies to respond to such international commitments involves great research efforts by Australia. Governments around the world are now responding to emission targets, and the need to develop alternative energy technologies and other sustainable generation systems is emphasised (Horne, Bates et al. 2007). The policies for zero emission developments fall under such emission reduction policy.

Policies are required on international, national and local levels. In Australia, on a national level, the national Renewable Energy Target (RET) and the Carbon Pollution Reduction Scheme (CPRS) are both examples of proposed policies. Furthermore, on a state level the Victorian Feed in Tariff (VFIT) is recently implemented. On a local level, an example of emission policies is one set by the Moreland City Council to reduce greenhouse pollution to net zero within the community by 2030.

Targets and policies for emissions reduction are set in different forms all over the world, and they definitely play a part in setting policies, aims and objectives for zero emission developments. Australia committed to the Kyoto protocol relatively late and it is therefore important to view successful international policies which enable individual, local and national action before setting its own policies. Both national and local environmental organisations should be a part of the policy creation process. Doing so would enable Australia to further create a policy response that really tackles climate change and allows for implementation of highly environmentally striving developments such as zero emission developments.

5.5 Implementation and Evaluation

Today, it is becoming evident that evaluation is increasingly becoming important in different kinds of implementation processes. Evaluation is vital for a number of reasons in terms of zero emission developments. A key outcome from evaluation of early zero emission developments is to show the positive outcomes, and prove to those sceptic of its performance, that it is functioning and that emissions are reduced. Furthermore, it enables building owners to establish if their passively designed house is performing as assumed. Assumptions regarding occupancy and building use often differ from their actual use (Steinbock, Eijadi et al. 2007). Hence, exploring the real operation of the development is valuable since it can identify flaws, so they can be corrected, but, again, also to use for demonstration to show the decreases in energy use achieved only through building more efficiently. Evaluation of other parts than the buildings is obviously also important, again to determine if estimated outcomes matches real outcomes. For example, unexpected equipment performance, behaviour of the co-generation plant or PV panels can be traced through evaluation and measurements. Keeping record of these measurements adds benefits both in terms of being able to correct identified issues but also to keep a record that persists even if key people are no longer working onsite or responsible for the development.

An often used model to certify that evaluation is part of the development process is the plan, do, check and act process, developed by W. Edwards Deming:

Figure 8: Deming's Plan, Do, Check and Act diagram (Arveson 1998)

Simply, this model can be explained with planning involving designing the development process and doing is implementing it. Check is the part linked with the evaluation, where the performance is measured. The measurements are then assessed and the results are reported, and the acting phase involves deciding on required changes due to the prepared measurement reports. The acting phase then again leads into a new planning phase for designing and revising the development (Arveson 1998).

Tools that can be used within a zero emission development to provide for the measurements are smart metering systems. Those systems are used in all the case studies outlined and they enable each individual to follow their energy demand, and also see the changes in energy use due to their behavioural changes. Such measurements initially create a more energy observant household, where each individual can be involved in decreasing their personal emissions, making the whole development perform better. Moreover, the metering systems provides good information on how much energy is used, what type of energy and when, to enable for the evaluators to propose more actions which can be taken to reach the aims and objectives of the particular development.

Defining, reviewing available technologies and abatement strategies and accounting for social, cultural and economic parts of the implementation are important parts of the initial steps for a zero emission development. To decide the actual scenario of the development, scenario modelling is required. In the following chapter, such modelling is performed along with a discussion about, and reasons behind, choosing certain combinations of technologies and strategies.

6 Scenario Modelling

As part of establishing a zero emission development the modelling of different scenarios is vital. It aims to present a range of options to achieve zero emissions. These scenarios depend on particular goals, set out by the project proponent, which may include achieving zero emissions through certain economic goals, social benefits, a particular community environment or specific environmental perspective. Presenting different scenarios enables the project proponent to consider both benefits and drawbacks of each scenario and pick one that suits their goals, aims and objectives.

The scenario modelling is closely related to the definition, and the aims and objectives, of the development. As defined, this thesis involves a zero emission development based on operational net zero emissions for stationary energy only. However, equivalent ways of working and similar technologies can be applied to both life cycle net zero and life cycle net negative developments, as long as the energy generation exceeds that of the annual demand and hence offsets embodied energy from construction.

Different approaches by developers are common. One developer may believe that the demonstration of the capacity of well-developed renewable energy technologies is the major purpose of zero emission developments. Such an approach could be reluctant to offset a large amount of emissions in any other way than feeding excess renewable electricity into the grid.

Another possible approach is the need for fast implementation of zero emission developments to have an early impact on rising climate change issues. More established, large scale energy providing technologies, such as gas fired co-generation, could then be utilised to get the project up and running as fast as possible. As a result, the released emissions would have to be offset through, for example, carbon sequestration or energy efficiency implementations in a precinct. Such approach enables the proponent to prove that relatively quick implementations are possible when creating zero emission developments.

When aims, objectives and definitions are established, an energy baseline for the modelling can be created, to properly estimate the required energy for the whole development. To estimate the energy demand, a range of factors has to be considered.

Some examples are:

- ✓ Amount of dwellings, offices and public spaces to be built.
- ✓ Energy demand in different buildings.
- ✓ Number of future inhabitants.
- ✓ Social/cultural aspects.
- ✓ Behavioural assumptions.

- ✓ Additional operational energy demand, for example street lights or public leisure centres.
- ✓ Possible increase or decrease in energy demand.
- ✓ Shape of the energy curve and time for peak demand.

It is not until an energy assessment is done and an approximate demand is estimated that the optimum combination of different available technologies may be considered. The more scenarios that are modelled, the more likely the project proponent is to find a model which suits the aims and objectives of the particular development.

To demonstrate scenario modelling a simplified 'hypothetical development sample' has been created to act as the energy assessment. After that, four different technology and strategy combination have been modelled. To establish the development sample and the four scenarios, a range of assumptions and simplifications have been made. It is important to stress that the modelled scenarios aims to provide a relative cost comparison between the scenarios and demonstrate possible technology combinations, depending on aims and objectives within the definition by the project proponent. This modelling also aims to show suggestions of technology and strategy combinations ranging from fast implementations to fully renewable energy technology supported scenarios. In reality, more than four scenarios need to be modelled, along with variations within each scenario. However, even though the estimated costs are based on simplified scenarios they provide a good base to compare initial costs with running and maintenance costs for each proposed scenario.

Below the *hypothetical development sample* is presented along with the four technology combinations. Assumptions made will be presented, and a cost and benefit analysis will be carried out, based on the outcomes of the different scenarios.

6.1 Hypothetical Development Sample

The purpose of the *development sample* is to do an energy assessment and estimate the future energy demand. The hypothetical development sample is assumed to cover an area of 10 ha, set in an urban infill. 1000 homes with an average of 80 m^2 are to be built, along with 30,000 m^2 of office and retail spaces.

To estimate the energy requirement of the area some assumptions are made;

- ✓ The area consists of 1000 homes and 30,000 m^2 of office and retail spaces.
- ✓ Every home is an average of 80m^2.
- ✓ An average of 4 people lives in each house.
- ✓ Each passively designed home and office space annually use 105 kWh/m^2
- ✓ Heating, cooling and hot water heating takes up 36% of the energy use in the houses and electricity takes up 64%.

- ✓ Moreover, simplifications are made since the modelling aims to give an overview to be able to compare the costs and benefits of different scenarios rather than demonstrating exact costs and energy requirements in a zero emission development.

The energy estimation of the area is as follows;

Table 3: Assumptions on energy output for *Development sample*

Hypothetical development sample			
Area	10	ha	
Houses	1,000	houses	
Size of house	80	m^2	
Amount of people	4	people/house	
Energy Use (heating and electricity)	105	kWh/m^2 and year	
Energy demand in dwellings	**8,400**	**MWh/ year**	
Retail and Office Space	30,000	m^2	
Energy Use	105	kWh/m^2 and year	
Energy demand in offices and retail spaces	**3,150**	**MWh/year**	
Total Energy Use	**11,550**	**MWh/year**	
Total hot water heating, heating/cooling (42%)	**4,158**	**MWh/year**	**5,000 MWh/yr**
Total electricity use (58%)	**7,392**	**MWh/year**	**8,000 MWh/yr**

The average energy in a house obviously varies with location, behaviour of residents and the design of the building. A general energy use for a passively designed house in Europe varies between 90-120 kWh/ m^2 and year (Passiv Haus UK 2008; WWF 2008). The chosen energy demand is 105 kWh/m^2 and year. According to the standards for the Passiv Haus, used for the BedZED development, about 15 kWh is used for heating and cooling (Passiv Haus UK 2008). This is similar to an eight star rated building in Melbourne according to the rating tool NatHERS (NatHERS 2008). The additional energy use is for hot water and electricity. There is not much information on the division of the energy between those two sectors within a PassivHaus or an 8 star rated house, so instead the Wilkenfeld typical household energy breakdown is used to estimate such distribution (Wilkenfeld 2008).

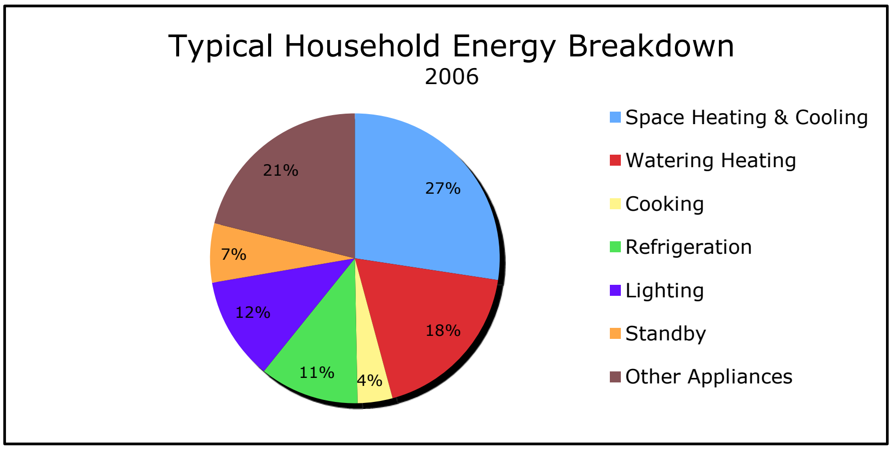

Figure 9: A typical household energy breakdown (Wilkenfeld 2008)

With 15 kWh used for heating and cooling, there is an additional 90 kWh to be split between hot water heating and electricity. According to figure 9, 18% of the remaining 73% (excluding heating/cooling) is used for hot water heating. Hence, about 25% of the 90 kWh (approximately 23 kWh) is estimated to be used for hot water heating. This results in 15+23=38 kWh being used for heating/cooling and hot water heating and 67 kWh being used for electricity demand. In total, approximately 64% of the total 105 kWh/year and m^2 are used for electricity demand and 36% for hot water heating and heating/cooling. With office space, the energy distribution between hot water, electricity and heating and cooling is extremely variable, hence a similar distribution to the household is used.

This assessment applies for operational energy, and some other simplifications worth mentioning are:

- ✓ Additional energy requirements, which could be seen as operational energy, are not accounted for. This could include street lighting, public spaces and other public applications.
- ✓ Variations in energy demand and the energy profile, such as peak demand, is not calculated but will be discussed.
- ✓ Increase in energy demand is not accounted for. However, within the development an increase in energy demand should not be expected, if the energy efficient designed buildings are up to standard.
- ✓ An allowance for fluctuations in demand and additional losses is made through increasing the supplied energy to be around 1.1 of the estimated demand.

6.2 Scenarios

Four different scenarios have been suggested to support the created energy demand of the development. Outcomes from all of the calculations for each scenario as well as references to energy output and costs are presented in appendix 1. Some assumptions made for all scenarios are:

- ✓ The price of natural gas is based on the Australian price at which natural gas can be bought in the commercial sector: 0.016 $/kWh (Bertsch 2009). However, calculations are also made with an average price of available European gas prices from Energy Information Administration: 0.0513 $/kWh (EIA 2008). The reason for using an average European price as well is to demonstrate the Australian gas price being very low, relative to the European market. Such difference encourages a discussion around how that may affect the choice of scenarios and technologies.
- ✓ Greenhouse gas emissions for the scenarios are based the emissions factor for burning natural gas in Victoria, Australia; 57.30 kg CO_{2e} /GJ (Australian Government 2008b).

(Note: For information on any calculations or costs discussed in the following chapter, refer to Appendix 1)

6.2.1 Scenario 1

The purpose of the first scenario is to demonstrate the possibility of offsetting emissions through retrofitting in a precinct. By involving a precinct, the impact that relatively simple retrofitting implementations in existing buildings can have, when reducing emissions, is demonstrated. A natural gas fired co-generation plant is installed to support both electricity and heating demand as well as hot water heating. All emissions are then offset through retrofitting.

Scenario 1 includes the following technologies and abatement strategies:

- 3.4 MW installed natural gas fired co-generation plant to support electricity, heating, cooling and hot water heating.
- Offsetting through draught sealing, replacement of incandescent light globes to compact fluorescent lights, ceiling insulation and efficient showerheads and flow restrictors and a change to an energy efficient fridge.

Assumptions and simplifications made were:

- ✓ The co-generation plant has an internal combustion engine with a size of 3.4 MW and an efficiency of 32.5 % based on average efficiency of proposed internal combustion engines for CHP (Lazzarin and Noro 2006).
- ✓ The co-generation plant operates 20 hours/day, to provide some time for possible maintenance.
- ✓ The pipes are estimated to be 3000 m, based on other developments with similar output (Strasa Konsultanti SIA 2008).
- ✓ Heat is delivered at 2 units to 1 unit electricity.

- ✓ Offsetting in the precinct is estimated to be 30% behavioural related and 70% due to retrofitting (see appendix 1) (Desmedt, Vekemans et al. 2009).
- ✓ Excess heat is not sold.

The outcome of the calculations for scenario 1 was:

Table 4: Approximate costs scenario 1

Scenario 1		
Natural gas fired co-generation, precinct energy efficiency		
Total investment cost co-generation	7,580,717	$
Total retrofitting cost	2,295,394	$
Total installation cost	**9,876,111**	**$**
Co-generation		
Annual fuel cost Australia	398,450	$
Annual fuel cost Europe	1,262,650	$
Annual maintenance cost	163,068	$
Retrofitting		
Total retrofitting cost	2,177,514	$
Total annual cost Australia	**561,518**	**$**

6.2.2 Scenario 2

The purpose of scenario 2 is to demonstrate a fast implementation of a zero emission development using a well established energy efficient technology. Hence gas fired co-generation is implemented for electricity, heating and hot water heating demand. The thought is then to pay for someone else to take care of the actual offsetting of the produced emissions. This demonstrates a simpler and faster implementation in comparison to scenario 1.

Scenario 2 includes the following technologies and abatement strategies:

- 3.4 MW installed natural gas fired co-generation plant to support electricity and heating demand.
- Offsetting of emissions through paying for an external source to handle it.

Assumptions and simplifications made were:

- ✓ The co-generation plant has an internal combustion engine with a size of 3.4 MW and an efficiency of 32.5 % based on average efficiency of proposed internal combustion engines for CHP (Lazzarin and Noro 2006).
- ✓ The co-generation plant operates 20 hours/day, to provide some time for possible maintenance.
- ✓ The pipes are estimated to be 3000 m, based on other developments with similar output (Strasa Konsultanti SIA 2008).
- ✓ Heat is delivered at 2 units to 1 unit electricity.
- ✓ Excess heat is not sold

The outcome of the calculations for scenario 2 was:

Table 5: Approximate costs scenario 2

Scenario 2		
Natural gas fired co-generation, payed offsetting		
Total installation cost co-generation plant	7,580,717	$
Total installation cost	**7,580,717**	**$**
Annual offsetting cost	**63,420**	**$**
Co-generation		
Annual fuel cost Australia	398,450	$
Annual fuel cost Europe	1,262,650	$
Annual maintenance cost	163,068	$
Annual offsetting cost	63,420	$
Total annual cost Australia	**624,938**	**$**

6.2.3 Scenario 3

The purpose of the third scenario is to implement a renewable energy technology, so the need for offsetting is eliminated. In this case a biogas fuelled co-generation plant is installed to support heating, electricity and hot water heating. Such technology is obviously newer and less established, so there is a higher risk involved in the implementation. However, it clearly demonstrates the possibility of renewable energy technologies supporting large energy demands.

Scenario 3 includes the following technologies and abatement strategies:

- 3.4 MW biofuelled co-generation plant to support electricity, heating and hot water heating requirements.
- 1.5 MW gasifier to produce biogas from woodchips.
- No offsetting is required.

Assumptions and simplifications made were:

- ✓ The co-generation plant has an internal combustion engine with a size of 3.4 MW and an efficiency of 32.5 % based on average efficiency of proposed internal combustion engines for CHP (Lazzarin and Noro 2006).
- ✓ The co-generation plant operates 20 hours/day, to provide some time for possible maintenance.
- ✓ The pipes are estimated to be 3000 m, based on other developments with similar output (Strasa Konsultanti SIA 2008).
- ✓ Heat is delivered at 2 units to 1 unit electricity.
- ✓ Excess heat is not sold.
- ✓ The gasifier has a size of 1.5 MW and an efficiency of 75% based on an average efficiency of gasifiers (Sanderson 2009)
- ✓ The biofuel used is woodchips. It is estimated that 1.4 tonnes of woodchips are required for the production of $1MWh_e$ (Sanderson 2009).

The outcome of the calculations for scenario 3 was:

Table 6: Approximate costs scenario 3

Scenario 3		
Biofuelled co-generation		
Total installation cost co-generation plant	9,772,498	$
Total installation cost	**9,772,498**	**$**
Co-generation		
Annual fuel cost	400,000	$
Annual maintenance cost	163,068	$
Total annual cost	**563,068**	**$**

6.2.4 Scenario 4

The purpose of the fourth scenario is also to support the development on renewable energy technologies as far as possible, particularly demonstrating the possible implementation of large wind and solar technologies.

Scenario 4 includes the following technologies and abatement strategies:

- 1,160 kW installed polycrystalline solar PV panels and 4,500 kW installed wind energy to support the electricity demand.
- 7,280 m^2 of solar collectors for hot water heating.
- A 15 hp (0.6 MW) natural gas boiler is installed to support heating and additional hot water heating.
- Offsetting of emissions through paying for an external source to handle it.

Assumptions and simplifications made were:

- ✓ The electricity output is about 6,700 MWh/year from wind and 1,300 MWh/year from solar.
- ✓ *Kyocera 130W 12Volt Multicrystal Photovoltaic Modules* are used as example panels (Energymatters 2009a).
- ✓ Peak sunlight hours are set to be similar to Melbourne (3.15 hours/day) (Shone, Stapleton et al. 2008).
- ✓ *EcoSolar 5.9 HE 270HS* is used as example for hot water heating (ATA 2009; EECA 2009). The panels are flat plate collectors, it is a mains pressure system and both thermo-siphon and pumped full systems are available. The system supports 80% of the hot water heating based on the expectations of the particular system. Energy requirements for hot water heating are also based on system estimates.
- ✓ Maintenance costs are estimated to be low for solar PV and collectors.
- ✓ *Proven 15 48 Volt 15,000W Wind Turbine with 25 m Tower Kit* is used as example wind turbine (Energymatters 2009b).

- ✓ The yearly output is based on average wind speed with an annual output between 15,000- 30,000 kWh, based on the annual output for the selected turbine (Energymatters 2009b).
- ✓ Maintenance cost is estimated to be medium for the wind farm in comparison to low for solar hot water and solar PV.

The outcome of the calculations for scenario 4 was:

Table 7: Approximate costs scenario 4

Scenario 4		
Wind energy, PV panels, boiler, solar hot water		
Total installation cost wind energy	46,893,815	$
Total installation cost solar energy	14,272,891	$
Total installation cost hot water heating	2,402,400	$
Total installation cost boiler	1,670,073	$
Total installation cost	**65,239,179**	**$**
Annual offsetting cost	**8,354**	**$**
Wind and solar		
Maintenance cost	Low/Medium	
Boiler		
Annual fuel cost Australia	52,488	$
Annual fuel cost Europe	166,328	$
Annual offset cost	8,354	$
Annual running cost	146,019	$
Solar hot water		
Annual running/maintenance	Low	
Total annual cost Australia	**206,861**	**$**
Area required for solar collectors	**7,280**	**m^2**
Area required for PV	**7,939**	**m^2**
Turbines required	**297**	**turbines**

6.3 Scenario Comparison

It is important to stress that these costs will vary depending on a range of factors, which will be discussed in the cost and benefit analysis. However, comparing them to each other gives a good overview of which installations are more expensive, how the running costs vary, additional issues that may be connected with different alternatives and also where the major costs lie.

For this comparison, a simple payback period along with the Net Present Value (NPV) is calculated. The NPV is calculated just considering the Minimum Attractive Rate of return (MARR) of 8%, and also by including an inflation of 4% and an estimated carbon price. For these calculations, a period of 15 years is used for the NPV.

Moreover, a sensitivity analysis, including different estimated MARR will be presented and analysed in the discussion.

The compilation of the four proposed scenarios turned out as follows:

Table 8: Comparison between the scenarios

Scenario	**1**	**2**	**3**	**4**
Area required for PV (m^2)	Na	Na	Na	7,939
Wind turbines required	Na	Na	Na	297
Area required for solar hot water (m^2)	Na	Na	Na	7,280
Installation PV	Na	Na	Na	14,272,891
Installation wind	Na	Na	N	46,893,815
Installation boiler	Na	Na	Na	1,670,073
Installation solar hot water	Na	Na	Na	2,402,400
Installation co-generation	7,580,717	7,580,717	9,772,498	Na
Retrofitting	2,295,394	Na	Na	Na
Total installation cost ($)	**9,876,111**	**7,580,717**	**9,772,498**	**65,239,179**
Annual maintenance cost ($)	163,068	163,068	163,068	146,019
Annual fuel cost Australia ($)	398,450	398,450	400,000	52,488
Annual fuel cost Europe ($)	1,262,650	1,262,650	400,000	166,328
Annual offsetting costs ($)	Na	63,420	Na	8,354
Total annual cost	**561,518**	**624,938**	**563,068**	**206,861**
Simple pay back (years)	**9**	**8**	**9**	**46**
1. NPV	-614,431	1,020,240	-641,961	-53,059,698
2. NPV including 4% inflation	1,786,186	3,278,339	1,755,173	-50,851,363
3. NPV with carbon price	2,779,402	4,414,074	5,133,567	-47,632,609
4. NPV with carbon price and 4% inflation	6,132,420	7,624,573	9,151,470	-42,912,016

6.4 Cost and Benefit Analysis

To model only four scenarios is generally not sufficient before making a decision on which will provide the best outcome in terms of set aim and objectives. Instead, these four scenarios are aimed to present a spectrum of combinations that could be suggested. They range from being completely dependent on renewable energy technologies, to the use of a well established energy efficient technology such as gas fired co-generation, paying to offset the produced emissions. Small variations of all these scenarios should be tested. A cost and benefit analyses is presented below for the set scenarios.

6.4.1 Scenario 1 and 2

Installing a co-generation plant in a zero emission development provides a large amount of the required energy needs.

If a gas fired CHP (Combined Heat and Power) is installed the issue of offsetting released emissions is present. In scenario 1, offsetting is done through fairly small retrofits of approximately 700 homes. The inclusion of a precinct has an important demonstration purpose, and it enables an increased amount of people to be part of the reduction in emissions. There is a risk involved with retrofitting and estimating emissions, due to the need for behavioural changes within the homes. These types of changes are hard to estimate, obstructing accurate measures. However, offsetting through actively involving more houses in decreasing their emissions enables emissions to be offset closely to the site, aiming to be zero within the boundaries, compared to just paying someone to offset the emissions outside of the development.

The purpose and benefits of paying an external source to offset the emissions can be a fast and initially comparatively cheap implementation. For a project proponent wanting to demonstrate that zero emission developments does not have to be extremely expensive or that acting quickly is part of the vital actions on climate change, this solution could be of great value. However, paying for external offsetting and not presenting any renewable energy technologies onsite may conflict with definitions, aims and objectives with certain project proponents.

Gas fired co-generation is a well established technology and the risk of breakdown or similar issues comparatively low. It is also easier over a shorter period of time, to develop a plant that will support the estimated energy demand of the development. These factors enable a fast development and a site ready to be used by, and demonstrated to, the public. Moving up to larger scale developments, a well established CHP is an option due to possible large and constant energy outputs from the technology.

The initial price involving retrofitting is obviously higher, resulting in a lower annual running cost due to the removed need for annual offsetting. Nevertheless, the annual cost still remains quite high for scenario 2, due the fuel and maintenance costs. In addition, offsetting through retrofitting may not rule out the offsetting costs completely. The offset emissions are compared to the standard savings of the year when the retrofitting is implemented. Such standards may change over time and hence fewer emissions are estimated to be offset through the retrofits each year.

In comparison to the other scenarios, the price of the installation show to be significantly lower than when installing solar and wind power, but there is a higher running cost to this type of energy production. The costs of running the plant may also vary depending on factors such as: efficiency of the engine used; the price of fuel; the possibility of selling excess heat; and possible costs for renovations. It is interesting to compare the annual fuel costs if the co-generation plant would be located in Australia, compared to the estimated European average gas price.

Table 9: Annual fuel cost comparison between avarage European and Australian natrual gas prices for scenario 1 or 2.

Cost natural gas Australia	4.5	$/GJ
	0.016	$/kWh
Total fuel cost Australia	**398,450**	**$/year**
Cost natural gas European average	0.051	$/kWh
Total fuel cost Europe	**1,262,650**	**$/year**

This table clearly demonstrates the dependency of fuel costs, resulting in a running cost just cheaper than that of the biofuelled co-generation plant. Such difference on cost of natural gas may have vast implications on the chosen technology, depending on the location of the development. Natural gas being so cheap in Australia, strongly pushes for an implementation using natural gas fired co-generation. However, it is vital to stress the predictions of Australian natural gas prices rising fast, influenced by world prices (Australian Federal Treasury 2009b) Also, the option of selling excess heat form the co-generation, due to higher electricity demand than heat demand could be an option in trying to reduce the annual costs for both scenario 1 and 2.

In these two scenarios, no renewable energy technology is implemented. Such an approach can be disadvantageous in many ways. Firstly, the site does not demonstrate renewable energy to the surroundings, enabling the discussion if it is at all possible to survive solely on renewable energy production. Being a zero emission development, demonstrating the possibilities of renewable energy is generally high on the list of priorities, and such discussion not beneficial. Secondly, using particularly solar energy to reduce peak demand is a great alternative, especially in countries like Australia, where peak demand occurs at the same time as the peak solar output from the PV panels. Moreover, using solar and wind energy to feed back into the grid when excess electricity is produced decreases the amount offsetting required and assists in being zero emissions.

Important outcomes from scenario 1 and 2:

- ✓ Offsetting through retrofitting is vital in an attempt to increase the involved amount of people in reducing emissions, and also to demonstrate the importance of decreasing emissions in already existing buildings.
- ✓ Using gas fired CHP forces the developer to offset the created emissions, which may also collide with set definitions, aims and objectives of the developer.
- ✓ Paying for offsetting may collide with definitions of certain project proponents.
- ✓ Natural gas fired co-generation is a well established technology, enabling a fast low risk implementation of a zero emission development.
- ✓ It could be an issue that no renewable energy technology is demonstrated on site.
- ✓ Installing gas fired CHP is initially a cheaper option compared to scenario 3 and 4, but the annual costs are generally higher. Particularly installing only a natural gas fired co-generation, as in scenario 2, is a cheap initial investment.

- ✓ The decision on using gas fired co-generation is heavily dependent on the national gas price of each location.
- ✓ PV electricity could be used for peak demand.

6.4.2 Scenario 3

Using a similar technology as in scenario 1 and 2, but avoiding the issue of offsetting can be made possible by running co-generation with biofuel. This further demonstrates a development only being dependent on renewable energy technologies. Additional installation costs should be expected due to the necessary implementation of a gasifier to produce biogas. The developed technology for biofuelled co-generation is not as well established, which could result in higher investment risks compared to scenario 1 and 2.

There are also risks regarding the fuel used. Those risks involve both the availability of fuel, the energy required to produce the fuel and varying fuel costs. The availability of fuel depends on the location and local industries surrounding the development. However, if such option is not possible, the fuel may have to be imported from a more distant location. Then the issue with embodied energy in the biofuel due to collection, transportation and gas production should be considered and a decision has to be made if any actions are to be taken to offset such embodied energy. Depending on where the fuel comes from, and what it is it, will obviously also vary in price, having an impact on the annual costs of the co-generation plant.

Larger scale issues which should also be considered include possible food shortage due to the origin of the biofuel. Either the land where it is produced or the actual crop used for fuel might otherwise be used for food production, and greatly affect the health of people. The best way to tackle such issues is to source waste products to act as biofuel, such as woodchips. These types of social issues also need to be evaluated before deciding on the type of fuel used.

The above discussion shows that before installing biofuelled co-generation plants, the fuel security and other issues is to be closely evaluated.

The fuel costs for this particular scenario shows to be lower than the cost of natural gas if compared to European prices of natural gas. However, if compared to the current Australian commercial price, the annual fuel costs turn out to be almost exactly the same. Even at times when the fuel-costs are similar, biofuelled co-generation can be a reasonable option, since it eliminates the offsetting costs, and hence lower the total annual cost. This applies particularly in comparison with scenario 2, which pays an external source to offset the emissions.

The installation cost is higher, depending on the installation of the gasifier, enabling the purchase of woodchips rather than biogas. In addition, it is vital to stress the possible variations in biofuel costs, which can have a great impact on the annual costs of the total implementation. A great option is a locally sourced biofuel, available as a waste product from another industry. Such biofuel can be wood chip or pellets. Otherwise, biogas can also come from biomass digesters or the use of landfill can be investigated. There is an example of producing biogas from inhabitants own food waste in the case study of Bo01. Such technology is new, and involves thorough risk assessment before being implemented. However, the exploration of such new technologies is vital when promoting zero emission developments and their importance. The risk assessment is hence heavily dependent on the biofuel used.

As for scenario 1 and 2, the option of selling excess heat from co-generation should be explored. Particularly in this scenario, selling excess heat would offset emissions, since it is produced from renewable energy. Since scenario 3 does not require offsetting from an operational stationary energy point of view, the offsetting could consider life cycle emissions.

Similarly to the natural gas fired co-generation plant, the additional need for electricity peak demand could be supported through solar PV.

Important outcomes from scenario 3;

- ✓ Using biofuelled co-generation could enable the site not having to offset any emissions.
- ✓ The choice of biofuel has to be well investigated and careful consideration on a range of issues has to be taken before implementation.
- ✓ Installing biofuelled CHP is more expensive than gas fired, but with good access to cheap biofuel, the annual costs can be kept lower.
- ✓ Solar PV may be needed for peak demands and seasonal variations.

6.4.3 Scenario 4

In scenario 4, polycrystalline PV panels are used for parts of the electricity production. The reason for this is the greater efficiency of those panels (ATA 2004), resulting in a smaller area needed for the installation. Since a significant area is already required, the possibility to decrease this area is vital. The amorphous PV panels are a considerably cheaper per m^2, but their inefficiency would result in a need for more panels, and the investment cost would turn out to be similar to that of scenario 4.

As shown in the presentation of scenario 4, it takes up an area of 0.7 ha which is quite a significant space. This becomes a problem particularly since additional 0.7 ha solar collectors are installed for hot water heating. Similarly the wind farm of 297 wind turbines will require additional space. It is possible that they could be placed outside of the development. However, since the implementation is set in an urban infill, it may require the wind farm to be located far away from the delivery point which adds additional electricity losses due to electricity transmission.

Scenario 4 involves a significantly larger investment cost than any of the other scenarios. This is often compared to a lower maintenance costs after installation. The electricity production on site will be relatively cheap after installation. But, since a boiler is needed to support heating and hot water heating requirements, fuel and offsetting costs are added onto the annual costs. Scenario 4 still has the lowest annual costs compared to scenario 1, 2 and 3. Due to quite small installation of boiler, and low heat energy use, scenario 4 is annually cheaper than scenario 3, including the biofuelled co-generation, even when paying European price for gas.

An alternative to installing a natural gas boiler could be using biogas to produce the heat energy. Additional installation costs for a gasifier is then necessary. Installation and biofuel costs are seen in scenario 3, and issues involved with biofuel already discussed. To avoid probable issues with biofuel, but still producing a development heavily dependent on renewable energy technologies, large solar and wind implementations are necessary. Using a natural gas boiler to produce the heat energy is a good alternative when it is decided that biofuel might not be suited in the particular area.

Other variations may include a larger electricity supply from wind energy, with solar PV supporting peak demand rather than base demand. If wind is determined to be suitable, that may decrease the initial investment cost.

Installation of wind energy requires detailed research on resource availability, and research up to at least one year in advance is vital to determine wind patterns and fluctuations over all seasons to provide a reliable possible outcome from the turbines. It is therefore important to realise that costs and available energy presented will vary with the wind availability and consistency on site. As seen earlier, wind turbines are heavily dependent on the wind speed and an increase in speed will have an effect to the power of three on the energy output. In areas where it is determined that wind energy is a suitable option, it will generally be cheaper than solar energy, and it also takes up less space. Costs may also be brought down by investing in fewer, but larger turbines, rather than many smaller ones.

Solar is dependent on the solar resources but such data is more easily accessible. Instead research involves types of panels and positioning of the panels for optimum outcome. For this scenario, the solar collectors play an important role in decreasing the energy demand from the boiler used for hot water heating. Both the technologies may perform better than estimated in the scenarios in areas where the conditions are optimum. Moreover, both wind turbines and solar panels may function as a great demonstration on the renewable action taken in the area.

This scenario is initially the most expensive, but with the lowest running costs. Nevertheless, in this case the demonstration of the renewable energy technologies has to be stressed. In addition, it is paramount to acknowledge that these implementations should be an environmental as well as an economic decision. If there is a market that is willing to pay more for sustainable building housing to live in a community with highly developed technology, being able to decrease their personal emissions, the implementation may very well be worth its initial high investment. Particularly if a zero emission development is built designed with housing attractive for this market, the investment can be justified.

These types of demonstrative implementations are also likely to attract funding. If the project is largely funded, an initial expensive installation cost could be justified.

Important outcomes from scenario 4:

- ✓ Large installations of solar and wind energy generally involve large investment costs but lower running costs.
- ✓ Space might be an issue when installing solar PV and solar hot water collectors.
- ✓ Solar and wind energy provides good and visible renewable energy demonstration on site.
- ✓ Producing heat energy from a natural gas boiler may be an issue in terms of not being a renewable technology. Biogas heat generation is a possible option.
- ✓ Wind energy requires careful research before implementation. In areas where the conditions are right, wind is beneficial.
- ✓ High installation costs may result in higher costs for the individual residents, but it may be likely that there is a market for more expensive sustainable housing, enabling the development to go ahead.
- ✓ Zero emission developments involving large installations of demonstrative renewable energy technologies are likely to attract funding, which can support the large installation costs.

6.4.4 Discussion

It is not claimed that any of these scenarios are the ultimate set up for a zero emission development. Instead it aims to highlight a few possible combinations amongst plenty of possible blends of technologies. The ultimate choice is dependent on the location of the establishment and the evaluation of suitable technologies. It is also based on aims and objectives of the project proponent. As seen, scenarios can vary from well established energy efficient technologies to completely relying on renewable energy technologies. Issues such as offsetting, the way of offsetting and the message sent will be part of the scenario selection. Obviously combinations of these scenarios or small changes within and between them need to be made, to provide an accurate comparison.

Some general key findings of the scenarios are:

- ✓ Co-generation is a good alternative in zero emission developments due to its efficient production of both heat and electricity. However, if operated by waste biofuel, that may add more to the value behind many definitions of zero emission developments.

- ✓ The decisions about co-generation are heavily dependent on the national fuel price.
- ✓ Biofuel involves great risk assessment and variable fuel prices.
- ✓ Solar PV is important to provide electricity output, and especially for peak demand.
- ✓ Wind and solar energy demonstrates renewable energy technologies and may supply excess electricity at times which can be exported to the grid to decrease offsetting.
- ✓ Wind energy can be a great electricity producer if the right conditions are found on site. It could then be a major electricity supply.
- ✓ Solar heat is especially good for water heating.
- ✓ Solar and wind energy generally have higher implementation costs, whereas a co-generation plant is less costly to install but more expensive to operate.
- ✓ Offsetting emissions can be done through operations such as retrofitting homes in a precinct around the development, feeding excess renewably produced electricity into the grid or paying an external source to handle the offsetting.
- ✓ Issues with offsetting, and definitions around it has to be solved at an early stage of the implementation.
- ✓ High investment costs for the implementation of renewable energy technologies may be more likely to attract funding due to its demonstrational value.

The introduction of a cost on carbon dioxide will also have an effect on the cost and benefit analysis of these scenarios. If carbon is adequately priced, it will make actions such as zero emission developments based on mainly renewable energy technologies more attractive. High initial costs may then be easier justified, due to a higher running cost for those developments which are still releasing emissions from the use of natural gas. It is also stated by the Australian Government that emissions pricing will increase the development and deployment of new renewable and low emission technologies (Australian Federal Treasury 2009a), forcing investment costs to decrease.

How exactly the pricing of carbon changes, is dependent on where the carbon cap is placed, and how it is reduced over time. Below, different stabilisation scenarios, or cap suggestions, are shown along with the expected cost per tonne of CO_{2e} released. The Garnaut and CPRS scenarios are both Australian measurements, representing outcomes under different estimates and assumptions.

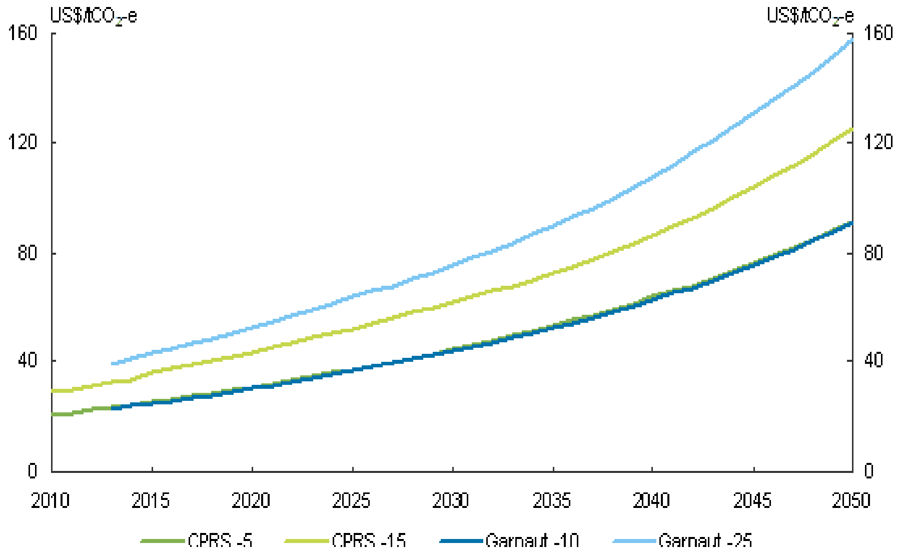

Figure 10: Carbon price depending on different cap scenarios (Australian Federal Treasury 2009)

Both Garnaut -10 scenario and CPRS-5 scenario aim for 550 part per million (ppm) of CO_{2e} in the atmosphere, whereas CPRS-15 scenario aim for 510 ppm and Garnaut-25 scenario aim for 450 ppm. This can be compared to today's level of 430 ppm of CO_{2e} of which about 380 ppm is CO_2 (Stern 2008). Also important is the estimation that low stabilisation levels of CO_{2e} in the atmosphere will involve higher national mitigation costs (Australian Federal Treasury 2009a).

The movement into a lower emissions future is obviously going to involve costs. However, it is important for Australia, as well as other countries, to participate in the action on reducing emissions. An early mitigation towards a lower emission future will reduce long term costs (Australian Federal Treasury 2009a). This puts zero emission developments and particularly those solely dependent on renewable technologies, in a different position. Considering the carbon price, based on the Garnaut-25 scenario, will increase around 400% in 2050 compared to 2010, the earlier much higher costs for solar and wind technologies may not be as significant any longer. Under this development, the demand for biofuels may rise, and both increase the running costs and decrease the fuel security for a biofuelled co-generation plant. Again, an establishment involving large solar and wind energy technologies can be an attractive choice.

Looking at the NPV for the different scenarios also gives an indication on which implementations are most economically justifiable. The NPV is calculated through looking at the running cost of the development if electricity, produced from brown coal, was imported from the grid. The cost of additional energy is estimated through buying natural gas as a household, rather than at a commercial price, for certain appliances. The efficiency is accounted for when calculating the total demand. All prices are based on present Victorian costs. The greenhouse gas emissions for the imported electricity is based the emissions factor for electricity in Victoria, Australia; 340 kg CO_{2e} /GJ.

Depending on who is paying the initial cost for the development the Minimum Attractive Rate of Return (MARR) that could have been achieved, if the money was invested rather than spent on the development, varies. Hence, a sensitivity analysis is performed comparing different MARR for the different scenarios.

This sensitivity analysis is performed for four different ways to calculate the NPV. At first it is done only considering MARR and the savings made, and secondly, the calculations involve an inflation of 4%. The third option involves accounting for an estimated increasing carbon price, whereas the fourth options accounts for both carbon price and inflation. The results of the calculations are shown below:

Table 10: Sensitivity analysis for different NPV's

MARR	5%	6%	7%	8%	9%	10%
1. NPV						
Scenario 1	1,330,005	617,034	-28,556	-614,431	-1,147,272	-1,632,915
Scenario 2	2,849,240	2,178,597	1,571,333	1,020,240	519,033	62,221
Scenario 3	1,299,654	587,718	-56,936	-641,961	-1,174,029	-1,658,968
Scenario 4	-50,469,723	-51,419,395	-52,279,317	-53,059,698	-53,769,439	-54,416,312
2. NPV including 4% inflation						
Scenario 1	4,526,128	3,516,533	2,607,133	1,786,186	1,043,487	370,149
Scenario 2	5,855,619	4,905,961	4,050,549	3,278,339	2,579,732	1,946,369
Scenario 3	4,491,142	3,483,011	2,574,930	1,755,173	1,013,552	341,191
Scenario 4	-46,212,508	-47,557,281	-48,768,597	-49,862,093	-50,851,363	-51,748,244
3. NPV with carbon price						
Scenario 1	5,487,572	4,493,851	3,594,730	2,779,402	2,038,450	1,363,650
Scenario 2	7,006,807	6,055,414	5,194,620	4,414,074	3,704,754	3,058,786
Scenario 3	8,374,883	7,185,175	6,109,069	5,133,567	4,247,341	3,440,501
Scenario 4	-43,821,344	-45,219,964	-46,485,308	-47,632,609	-48,675,141	-49,624,496
4. NPV including inflation and carbon price						
Scenario 1	9,960,353	8,548,931	7,278,480	6,132,420	5,096,345	4,157,713
Scenario 2	11,289,843	9,938,358	8,721,896	7,624,573	6,632,590	5,733,932
Scenario 3	13,738,950	12,047,002	10,524,495	9,151,470	7,910,590	6,786,758
Scenario 4	-37,522,622	-39,509,958	-41,298,631	-42,912,016	-44,370,425	-45,691,539

For all scenarios it can be seen that the investment becomes more beneficial with a decreasing MARR. Initially, scenario 2, including only gas fired co-generation, shows to be the scenario which gives the highest NPV and hence is the economically most justifiable. However, both scenario 1 and 3 shows a positive return at a MARR of 5-6%.

As mentioned, the second calculation of the NPV involved inflation. Generally, in Australia, the inflation rate has been between 3-4%. In the case of accounting for the inflation, it is estimated that the first savings are calculated on the value of the dollar at the end of that year (for calculations see appendix 1). The NPV value obviously increases, or decrease in loss, for all scenarios when accounting for inflation. In this case all scenarios 1 to 3 shows to be a beneficial investment, with the second scenario still being the economically most justifiable. It is still important to notice the NPV of scenario 1 and 3 being very similar, where in the third scenario the need for offsetting is completely eliminated. Such observation shows that a scenario fully dependent on renewable energy technologies can compete with that of the energy efficient technologies.

The above discussed carbon price has also been added on to the annual running costs, and was incorporated into the third NPV calculations. The carbon price used for these calculations is that for the Garnaut-25 scenario seen earlier, based on estimated costs for three intervals. The intervals are shown below:

Table 11: Carbon cost intervals

Year	$ (AUD)
2010-2015	56
2015-2020	63
2020-2025	70

The cost is added on both to the imported cost of energy and electricity, but also to the running cost of the natural gas fired co-generation plants and the boiler. Due to this, such analysis has the most effect on scenario 3 which produces no emissions at all as it operates, and also for the fourth scenario which is largely supported by renewable energy production.

Considering the carbon price have quite a significant impact on the NPV of the different scenarios. Particularly scenario 3 and 4 are affected by the inclusion of a carbon price, since they are not at all, or only marginally, dependent on natural gas. The most important outcome of the third NPV calculation is that the third scenario, the biofuelled co-generation plant, shows to be the economically *most* feasible alternative out of all the suggested options.

A comparison between the expected return for scenario 1, 2 and 3 depending on the different NPV calculations is shown below. The third scenario becoming the most feasible option when accounting for a carbon price and also inflation and a carbon price is here quite evident:

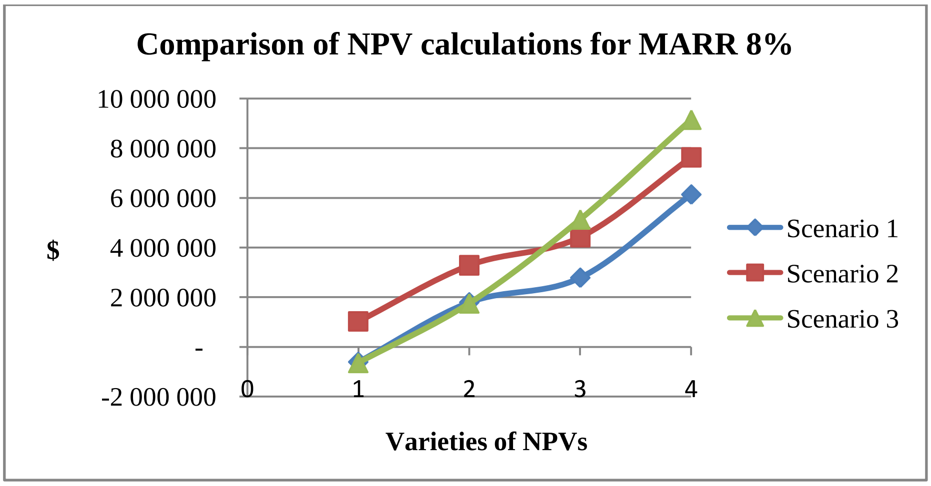

Figure 11: Comparison of the four different NPV calculations for scenario 1-3

1. NPV	**2. NPV including 4% inflation**
3. NPV including carbon price	**4. NPV including inflation and carbon price**

Since both inflation and carbon price have an impact on the NPV, the NPV including both of these was finally calculated. The fourth scenario does still not show to have a positive NPV, but the loss has decreased dramatically compared to the initial calculations. The third scenario still shows to be the most beneficial investment, strongly pushing for biofuelled co-generation where biofuel is estimated to be securely available at a reasonable price.

A cost analysis can also be affected by a private developer and a government borrowing the money prior to investment. The interest at which the government borrow may be more beneficial. Governments can often borrow at lower rates than most commercial institutions. Different state and national governments have ratings to get funds at different rates, and this will obviously affect the analysis. The lower rate of funding for governments will on the other hand only affect the cost analysis if it is the government that is borrowing money for it.

In summary, it is important to notice the great impact an estimated carbon price actually has on the economic benefits on these developments. The fourth scenario is still much more expensive, but there is a possibility that those costs will decrease with increasing knowledge and larger production of both solar and wind technologies. The NPV analysis shows the importance of including future probable costs for emissions. There are still other economic benefits raising form environmental benefits, which are not calculated here, but that can have an additional positive effect on the NPV for the scenarios more dependent on renewable energy technologies, rather than energy efficient technologies. For future implementations, and to justify high initial costs for zero emission developments, a price on environmental benefits could be very important to consider.

To provide some examples of existing zero emission developments using different definitions, technologies and strategies, three case studies have been outlined.

7 Case Studies

The case studies differ in terms of location and implementation and have as mentioned been performed to provide some reality anchoring to the proposed scenarios and definitions. These case studies include BedZED in the UK, the Dockside Green in Canada and Bo01 in Sweden.

7.1 CASE STUDY 1- Beddington Zero Energy Development

7.1.1 Project description

Beddington Zero (fossil) Energy Development say to be one of the first carbon neutral eco-communities built. It is located in Sutton, just 40 minutes south east of London. BedZED is a compact urban development covering 1.7 ha, that holds 82 residential homes and around 0.25 ha of commercial live and work space (Lazarus 2007a). Today around 220 people live onsite (Hodge 2007). The homes are a mixture of houses and the project also includes an exhibition centre a nursery and flats used as showcases for visitors to see what it is like to live in BedZED. It was initiated in 2000 and finished in 2002 setting the blueprint for sustainable living in the UK (The Peabody Trust 2008).

BedZED was designed to be a carbon neutral development, meaning net zero CO_2 released over a set time period. By defining it to be carbon neutral the developers also refer to the operation of the development. However, even if the construction was not carbon neutral, strong efforts were made to make it sustainable. The zero energy approach is achieved both by reducing the energy need in buildings but also by supplying the actual energy consumed by low-or-no carbon renewable energy sources and technologies. Surplus renewable energy is fed into the national grid at times of excess and electricity is imported when the renewable energy technologies do not produce enough electricity. The balance of feeding to and importing from the grid is designed to result in no net addition of CO_2 to the atmosphere over a set time period. The philosophy throughout the whole project is to capture and implement the environmental aspects and awareness in as many ways as possible. Strong emphasis is put on sunlight access, waste water recycling, solar energy, roof gardens and sustainable materials (The Peabody Trust 2008).

7.1.2 Background

If everyone lived as an average UK citizen, an equivalent of three earths would be required. The original idea of BedZED was to create a well developed community, without sacrificing comfort or modern living, as a remedy to our current unsustainable lifestyle. The goal was to show that we today have the knowledge and capability to live sustainably if the choice is made to do so.

An important aspect of the development is the location. The UK imports about 70% of its nutritional requirements and most of the surface that is capable of producing crops are already being cultivated (BioRegional and BRECSU 2002). In terms of thinking long term sustainability, woodland and forest are required for biomass energy, wood for construction and also importantly for biodiversity. Hence, the BedZED developers found it not sustainable to build on agricultural land or where forest today exists and that the development should be restricted to already existing brownfield sites. This is to avoid extensive use of land which already provides for the country and to avoid the evolvement of a green belt around already existing cities.

The UK has an issue with space due to an increase in both age and number of people within the population. Also, single and divorced people having their own housing are becoming more common. The Government predicts a requirement for approximately 3.8 million new homes in England by year 2021. If these were built with a current average density for new developments, they would cover an area larger than Greater London (BioRegional and BRECSU 2002). Hence a high build-density approach was taken in BedZED to reflect on the importance of using limited land resources to its maximum. Apart from new housing, new compact urban developments also need open space, community leisure, health and educational facilities, and location for employment. All this was implemented when designing BedZED to make a successful brownfield site development with future value for replication.

Important aspects for the initiation of the project were the involved partners and the triple bottom line approach taken.

Partners

BedZED was initiated, designed and developed by BioRegional Development Group and Bill Dunster Architects. The land owners are London's largest housing Association, the Peabody Trust (Lazarus 2007a). However, the Sutton Borough Council and its devotion to sustainability, has also played an important role in the development as the initial owner of the land. The BedZED development nearly fell through when another major builder put in a higher bid than the Peabody Trust. As the local authorities have an obligation to accept the higher offer, BedZED had to present before the environment secretary for approval. The only reason the Sutton Council could then sell to the Peabody Trust to a lower price was due to the permission to take environmental and social benefits into account (Rashleigh 2007). The BedZED development here demonstrates an example of how environmental costs can be accounted for, and impact on an economic decision.

Triple-bottom line

Even though high environmental achievements are paramount to the BedZED development it was realised that this could not be achieved in a long term aspect without ensuring that financial effectiveness and social amenity was implemented along with environmental goals.

A 'BedZED Sustainability Triple Bottom Line' was set up:

Table 12: Triple Bottom Line used in BedZED (Twinn 2003)

Social amenity	Financial effectiveness	Reduced environmental impacts
Mixed tenure, home type and occupiers	Housing association build costs	Zero fossil fuel
Living and working community activity	Affordable/key worker accommodation	100% renewable energy use
Urban density community critical mass	High demand for private sale elements	Zero rating homes
Proximity to wider community facilities	Commands margin over market value	Passive solar heating
Private open space for home	Planning gain to add development value	PV power for 40 electric vehicles
Sunlight and daylight amenity	Live/work to assist business start-ups	50% reduced potable water
Air quality comfort	Links improve public transport viability	On-site ecological water treatment
Reduced need for car	Addresses fuel poverty	Wind-powered ventilation systems
Local car pool	Low energy running bills	Low embodied energy
Community-led management	Internet links: community/local businesses/ service	Recycled timber Reused structural steel
Community internet		Improved site ecological value
Individual choice of carbon free lifestyle		Urban tree waste bio-fuelled CHP
		Land and finite resource
		Bike facilities
		Recycling facilities

Apart from being carbon neutral BedZED meets targets on an economic and social scale. Implementing BedZED under an integrated approach such as the triple bottom line made it more likely to become a successful development keeping the inhabitants at comfort and at the same time affordable.

7.1.3 Sustainable Technologies and Construction

The environmental impacts of extracting, processing and transporting material used for building is immense. The approach taken by the BedZED developers was that every aspect of the construction was considered in terms of environmental impact. All the materials chosen were aimed to have a low environmental impact, achieved by sourcing locally, and using as much reclaimed and recycled material as possible, minimising the embodied impacts (Lazarus 2007b).

To achieve the zero emission development goal of a zero emission site a ‘total energy strategy’ was implemented. This strategy consists of four main objectives (BioRegional and BRECSU 2002):

» Energy-efficient design of the buildings, involving water harvesting and treatment.
» Implementation of a biofuelled Combined Heat and Power plant
» Photovoltaic solar collectors for electricity production on sunspace roofs
» A green energy transport plan

Passive Solar and Wind Design

The design principles used for the BedZED housing is referred to as Passiv Haus. The standards of Passiv Haus were originally developed in Germany and Sweden but are now more broadly used within the EU (Thompson 2007).

To actively reduce energy demand within the dwellings a combination of energy conservation and passive design was utilised. A super insulation added to the roofs, walls and floors keeps the building warm. Due to the extra insulation, sunshine, human activity, lighting and hot water provide all the heat required within the building. The stored heat prevents overheating in summer and is slowly released on colder days to ensure a comfortable indoor temperature on colder days (BioRegional and BRECSU 2002).

The placing of housing and employment and community spaces was also well planned. By placing the employment site in the shade zones of the housing terraces, the tendency for overheating in summer, and the use of air conditioning was avoided during those hours when the offices are utilised. Large south facing windows was implemented in all buildings to utilise as much sunlight as possible (BioRegional and BRECSU 2002).

Signature features of the BedZED development are the wind cowls. They are constructed to combine passive ventilation and heat recovery. Ventilation is particularly important due to the increased insulation and air tightened doors and windows. These wind cowls are a key principle in the Passiv Haus design (Thompson 2007).

Water efficiency was also implemented into the buildings, investing in water efficient taps and shower heads, low flush toilets, water efficient washing machines and dishwashers and smaller bath tubs. Another innovation is an on-site sewage treatment system. It is a biofiltration system that purifies blackwater into greywater, which can be utilised for flushing toilets and watering the gardens. Energy is hence saved on not having to purify all water used within the household. In addition, rain water collecting tanks are placed on the roofs which stands for 18% percent of all the water utilised (Hodge 2007).

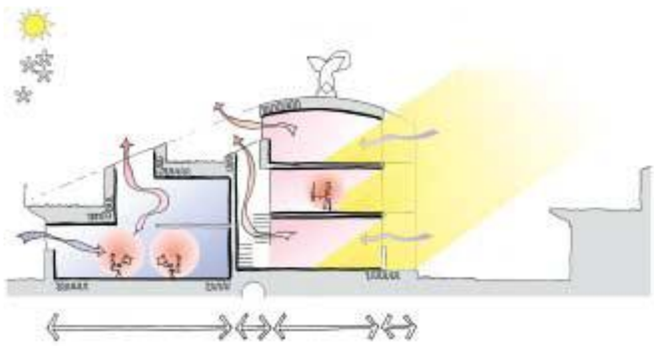

Figure 12:Passiv Haus Design (Twinn 2003)

Biofuelled CHP

A Combined Heat and Power plant (CHP) distributes hot water around the development for district heating as well as it generates electricity. The total electric output of the CHP plant is 130 kW_e (BioRegional and BRECSU 2002) and is able to supply the BedZED inhabitants with both sufficient heat and electricity due to: the reduction of average loads; the efficient design evening out normal fluctuations; and the mix of domestic and commercial housing, which evens out the daily electric demand (BioRegional and BRECSU 2002). The generator is fuelled by a mix of hydrogen, carbon monoxide and methane gases produced through a gasification of wood chips. The wood chips come from waste from the tree industry and was previously used as landfill (Twinn 2003). Finding waste streams to use as raw materials is vital in an attempt to become more sustainable. The utilisation of wood also enables the plant to be carbon neutral since the tree has sequestrated carbon dioxide throughout its lifetime.

Photovoltaic (PV) Solar Collectors

There is an installation of 777 m^2 of PV panels on the roofs of the houses in BedZED (Twinn 2003). Originally the PV cells were thought to power all the buildings electrical needs. However, providing electrical power to buildings has a payback period of about 70 years in the UK and the CHP alternative was seen as much more cost effective. Using the electric output to power electric cars was shown to be much more cost efficient and the payback dropped about five times when the electricity was used to displace transport fuel instead (BioRegional and BRECSU 2002). Today the PV panels electric output powers 40 electric cars within the area (Twinn 2003).

Green Energy Transportation Plan

The BedZED project introduced the very first legally binding Green Transport Plan as a condition for their planning permission. According to the BedZED developers, seeing transport is typically one third of a country's energy use (BioRegional 2000), a zero emission development should address transport issues. The prediction is that the transport energy consumption in BedZED will decrease over time as the implementation of the Transport Plan is occurring. There are three main parts of the energy plan including: *reducing the need to travel; promoting alternatives;* and *reducing impact of car use.* These are to be achieved through a mix of implementation such as the option of working on site, good public transport facilities, car pooling options and electric cars.

7.1.4 Discussion

Issues

As described a total carbon balance was considered for BedZED, with surpluses of renewably generated electricity from CHP and PV being feed into the national grid. With a phasing in of the Green Travel Plan and electric cars, inhabitants were to be given the option to reduce their impact on global warming to zero. However BedZED is not carbon neutral at present. Between 2002 and 2005 the CHP plant was operational making the development zero emissions (Riddlestone 2006), but being a prototype, there has been some issues with the plant. In 2005 the CHP plant blew a gasket forcing the residents to import electricity from the national grid (Rashleigh 2007). But, even when importing electricity the residents still have reduced their emissions by 56% compared to conventional housing in the UK.

Moreover, when designing the low energy demanding dwellings and employment spaces, different thermal analysis issues were raised. The issue was raised with the large range of parameters impacting on thermal passive design such as the available heat within the building and the estimation of glazing needed; being both the largest heat loss and gain. Steady state heating taking a long time to pass through the thermal walls, and also being dependent on changing indoor conditions, not always reflecting the reality and its demands, was another issue the constructers were faced with (Twinn 2003). This is today reflected in the evaluation by the people living in BedZED. Some residents find the passive design to work well whereas others have problems with a range of implementations. Typical complaints are the lack of fresh air in the houses, over heating due to large windows, and the reduction in energy bills does not always outweigh the discomfort expressed (Rashleigh 2007).

Initially the idea for the CHP installed in BedZED was to operate it under ambient energy harvested from the site itself. Energy was proposed to come from solar PV's, solar thermal and small wind turbines. However, this was proven to not be feasible economically. As mentioned, it was much more cost effective to use the PV electricity output for cars. Similar issues have been seen in the scenario modelling performed, where wind and solar solely used to supply larger developments with energy struggle to be economically feasible.

The total cost for BedZED turned out to be 30% higher than initially expected resulting in the average price of an apartment on site to be around 20% higher than in a conventional development in a similar area (Hodge 2007). Financial effectiveness being one of the three parts of the triple bottom line is not completely implemented with such additional costs. However, similar miss calculations are often made within conventional developments, often ending up costing way over the initial budget, making BedZED no different.

One of the most disappointing aspects for a lot of the residents is that the desired zero carbon living actually failed to materialise. Being as BedZED expresses it, carbon neutral, was the driving force for a lot of people to move into BedZED, and they are now disappointed that their attempt to be so, has failed (Rashleigh 2007). The CHP plant is under investigation to be either replaced or repaired to return to a carbon neutral community.

There have also been issues regarding the rainwater catchments. Unfortunately, the rainwater have reported to be contaminated by the green roofs which it is filtered through, being a potential health risk with the e-coli bacteria as the main problem. Calculations have shown that the water gained from the onsite sewage treatment have been sufficient to supply water to all existing toilets and hence the rain water catchments are not needed, being diverted to soak away (Parliament UK 2006).

Achievements

It has been showed that when selecting construction materials, major environmental achievements can be made without additional cost. For example, 15% of the total used material was reclaimed or reused being cheaper or costing the same as conventional material. This applied even after including the cost of additional time used by the staff to locate such material (Lazarus 2007b). The sustainable construction approach succeeded in reducing the embodied energy by 20-30% compared to the conventional average (Lazarus 2007a).

A great achievement lays in the water efficiency implementations in BedZED and on average the inhabitants use 76 litres/day and person. In comparison to the current strive by the Victorian Government to reach a daily use per person of 155 litres/day, that is an extremely water efficient community.

Creating awareness was one aspect that was found important while creating BedZED. In all units, electricity, gas and water smart meters were on display behind a glass panel in a prominent position in the kitchen. The smart meters enable residents to keep track of their use of resources. Given the possibility to see when more or less energy or water is used provides the residents with the power to individually connect certain behaviour with high or low energy and water use. Having the feeling of personal control is an important aspect when trying to involve the community in a sustainable living.

7.1.5 Conclusions

This case study shows parts of the problems and the extensive planning involved with creating a zero emission development. Despite issues that have evolved during and after the construction of BedZED it has still shown that it is technically, economically and socially feasible. Being one of the first and biggest zero emission developments, or Zero

Energy Developments in their own terminology, BedZED has played an important role in creating the world's first zero carbon policy proposals (Riddlestone 2006) in an attempt to make zero carbon homes part of conventional building industry. Even though BedZED only accounts for a new development in the brownfield and not a precinct, it still avoids adding to the problem of global warming and there is a proportionally less pressure on making already existing housing, industries and transport more energy efficient.

7.2 CASE STUDY 2- Dockside Green

7.2.1 Project description

The Dockside Green expresses their development to be a greenhouse gas neutral development. It is located in Victoria, British Columbia in Canada and currently under construction on a 6.05 ha former brownfield site. The plan is to be a global showcase in environmental social and economic responsibility towards a more sustainable future (Sustainability Victoria 2008b). Dockside Green will be ready for occupation during 2009 incorporating a mix of residential, commercial, retail and light industries buildings. At build-out, the development will house about 2200 residents in 1100 dwelling units (The Sheltair Group 2007).The strategy used for the development recognises the triple bottom line components, emphasising on a healthy and inclusive community with new economic opportunities and a high quality of life but with a minimal impact on the environment (Vancity and Windmill West 2008).

The Dockside Green uses the expression greenhouse gas neutral to define their development. By being greenhouse gas neutral the developers are not just considering the finished site, but rather the whole implementation process. By initially building a biomass heat generation plant to provide for further construction and with the purchase of green power certificates, the project aims to be greenhouse gas neutral from a building energy perspective as well as an operational one. The energy sector considered for this statement is stationary energy use. Current calculations, by the developers themselves, even show that the Dockside Green has a possibility of being greenhouse gas positive from an energy use perspective, when actually completed (Dockside Green Vancity et al. 2007a). Hence Dockside Green can be explained as a life cycle net zero or even life cycle net negative development.

7.2.2 Background

The Dockside Green is based on several rising environmental issues. Firstly, climate change is a major environmental concern and buildings are responsible for 33% of the produced emissions. Moreover, even if water is not scarce in Canada the capital and energy costs of treatment and also increasing climate change impacts affect the supply (Dockside Green, Vancity et al. 2007a). Therefore, the Dockside Green project has strong emphasis on water conservation and energy efficient building design.

Back in 2002, the City of Victoria decided to market the Dockside lands and make it available for redevelopment. It was then a contaminated site and the decision to make it into a sustainable community project was made in 2004. The project partners selected were the Windmill Development Group and Vancity Enterprises Ltd, who proposed an affordable and ecologically sustainable community development. The Master Development Agreement and Sales Contract was signed in 2005, and the site is to be available for residents in 2009 (The Sheltair Group 2007)

The partners committed to developing the Dockside lands using a Triple Bottom Line approach balancing economic development and benefits with social and environmental benefits.

Triple Bottom Line

From the initial stages of planning the Dockside Green project, the emphasis of the Triple Bottom Line has been strong. The commitment to the plan is evident throughout the whole project outline. The approach is based on the interaction between Natural Ecology, Economics and Social Equity and realises that these three components can never be treated as individual targets.

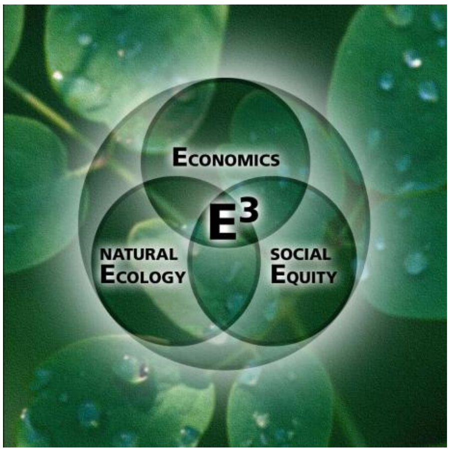

Figure 13: The Triple Bottom Line used for the Dockside Green development (Dockside Green, Vancity et al. 2007b)

Interconnecting environmental, economic and social objectives making sure they all improve the performance of each other makes it difficult to actually address under which specific Triple Bottom Line component each strategy lies. This makes the planning process harder and more enduring, but with the goal for a longer lasting outcome.

A significant part of the approach is not to see everything from an economic perspective, believing that economics determine what can actually be done from both an environmental and social perspective. While this is true to a certain extent, the goal is to pinpoint design possibilities which enhance all the factors, demonstrating that environmental commitment will have long term benefits such as job creation, improved marketability and energy cost savings (Vancity and Windmill West 2008). For example, a potentially more expensive green building strategy of a building is intended to decrease infrastructure costs, reduce greenhouse gases but also create natural habitat and improve human health. Dockside Green believes that their ability to exploit the whole-system approach is critical to future success in terms of ecology as well as social and economic benefits.

7.2.3 Sustainable Technologies and Construction

Due to the large environmental impact from the creation and transportation of material and also throughout construction, Dockside Green has made the decision to be greenhouse gas neutral in terms of energy building perspective. As mentioned this is aimed to be achieved through the early construction of a biomass heat generation plant. In addition the construction of the site will be provided with electricity by green powered certificates.

To achieve a greenhouse gas neutral or maybe even greenhouse gas positive community along with a water efficient development, the Windmill Development Group and Vancity Enterprises are implementing several energy and water related designs and technologies;

- » Passive Building Design
- » Biomass Heat Generation
- » Sewage Treatment Plant
- » Alternative Transport Plan

Building Design

To enable the development to sustain its goal of being a greenhouse gas positive community, the energy use of all buildings is vital. The Dockside Green project partners have adopted a green building rating tool to assess the environmental impact of their buildings. The adopted system Leadership in Energy & Environmental Design (LEED) is a 70 point rating system administered by the Canada Building Council and the United States Green Building Council. The system includes five principal categories; *Sustainable Sites*, *Water Efficiency*, *Energy and Atmosphere, Materials and Resources* and *Indoor Environmental Quality*. Points are achieved by fulfilling requirements in each category and an overall rating of platinum, gold, silver or certified is awarded for a building or a project. The Dockside Green strives to achieve LEED Platinum certification on all buildings that can be evaluated by the model. Today the two first residential phases, Synergy and Balance are in line with the set LEED platinum target (Dockside Green, Vancity et al. 2007a).

To achieve the standards of LEED a passive building design is implemented. The design includes 4 pipe fan coil system, low e double glazing and exterior blinds for heat gain and protection. Moreover, energy efficient lighting is installed in all dwellings and commercial buildings along with a devotion to avoid light pollution. Front loading washing machines and condensing dryers are selected that will use less energy than traditional machines (The Sheltair Group 2007). A smart metering system showing domestic hot and cold water use, heating bills and electricity usage is also to be installed, which allows the residents to make personal adjustments. It is estimated that the buildings will use 45-55% less energy than similar conventional Canadian buildings (Sustainability Victoria 2008b).

Biomass Heat Generation

One of the larger renewable energy technology implemented on site is the Biomass Heat Generation plant. The plant will be run on waste wood. The waste wood, along with water and air goes through thermochemical gasification. Such process produces gas from the waste wood, which is then cleaned to ensure no smoke is emitted when the gas is later burned in the plant (Sustainability Victoria 2008b). Early on the idea of generating electricity from the biomass was considered. It has not been completely excluded but at this point it is not feasible.

In the initial state of the project, the heat will be used for the development of the site. The thought is also that surplus heat will be made available for sale to neighbouring properties, creating greenhouse gas credits to off-set greenhouse gases created on site by importing electricity and delivering waste wood to the site. Further down the track, a district heating system will transport the generated heat to the residential and commercial buildings. To displace the use of natural gas on site a Memorandum of Understanding is set up with off-site customers (DocksideGreen, Vancity et al. 2007a).

Solar and Wind Technology

The current stated goal in terms of renewable energy technologies is to '*demonstrate various renewable energy systems and environmental techniques at Dockside Green*' (p24,(Dockside Green, Vancity et al. 2007a)). PV panels will be installed on buildings and solar lights will be used at bus shelters, for street lights and for traffic signals. In demonstration purpose, the Dockside Green Sustainability Centre will be established for visitors to get an overview of the utilised technologies on site (Sustainability Victoria 2008b). Other examples of both solar hot water technologies and wind turbines will be distributed on the site as demonstration. As a sustainability goal, these products are to be local products (from British Columbia) (Dockside Green, Vancity et al. 2007a).

Water Treatment and Efficiency

In Canada, the average potable water use is 340 litres per person and day, which is twice the European use (Dockside Green, Vancity et al. 2007a). Due to this fact and as part of the LEED commitment the Dockside green aims to have a well implemented water conservation program. The intention is that potable water, supplied from the regional water system, will be used for drinking, bathing, watering and washing. On site a sewage treatment and water re-use program will be installed and water from this will be used to flush toilets, for irrigation, green-roof garden maintenance and for onsite water features. The sewage treatment process is manufactured by a Canadian company and 100% of the sewage will be treated on site (Dockside Green, Vancity et al. 2007a).

The installed appliances such as dishwashers, toilets showers and washing machines will all be water efficient star rated appliances (Dockside Green, Vancity et al. 2007b).

An overview of the implementation is shown below:

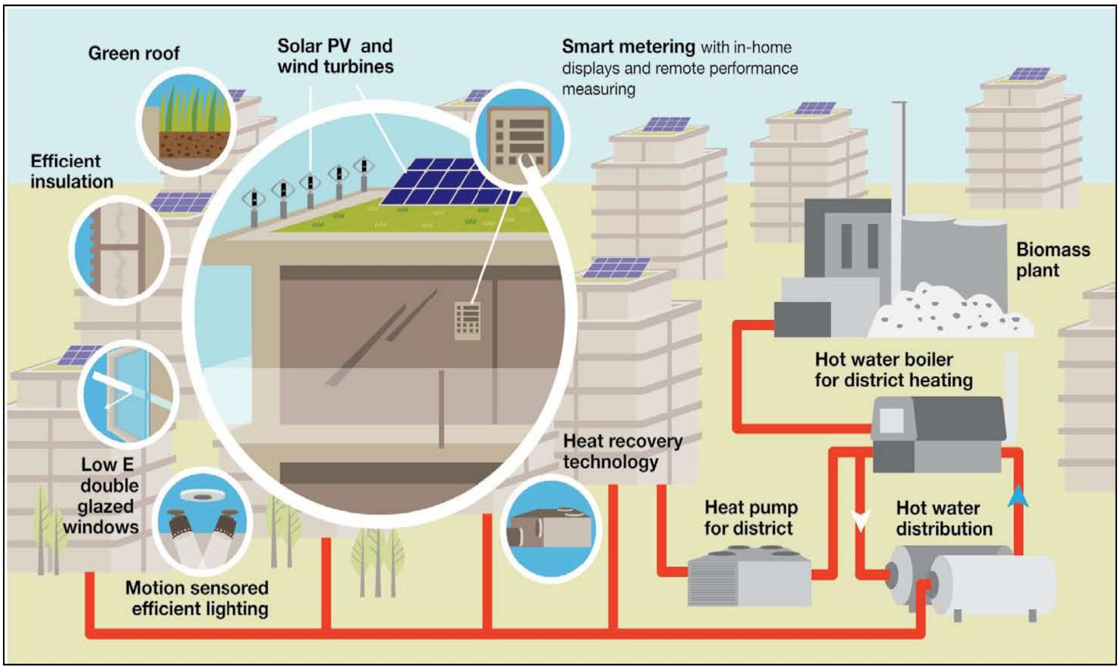

Figure 14: Renewable energy and water implementations at the Dockside Green (Sustainability Victoria 2008b)

Alternative Transport Strategies

The Dockside Green development also holds a transportation plan that aims to reduce resident's reliance on car transportation. On site the encouragement for walking is strong and many trails and walkways will be developed. The so called Galloping Goose, which is a regional bike trail, will be upgraded to the benefit of the residents of Dockside Green (Dockside Green, Vancity et al. 2007b). A local car share program is being developed, and 10 cars are purchased for this purpose. The car parking will be sold separately from the units, enabling those who do not own a car, not having to pay for a garage. Instead bike storage will be provided by all residential and commercial buildings. The opportunity to work on site will be given, which is aimed to reduce the need for transportation (Dockside Green, Vancity et al. 2007a).

7.2.4 Discussion

Issues

As discussed the construction of the site is to be made greenhouse gas with the early implementation of the biomass heat generation plant. However, it is not stated if the construction of this particular plant is also aimed to be greenhouse gas neutral. If that is the case, the construction of the heat generating biomass plant has to be offset somehow, and if that is not done it can be argued that the site is not greenhouse gas neutral from a building energy perspective. Furthermore, the plant is built for the capacity it is aimed to achieve in the future, due to a slowly increasing demand throughout construction this results in that the heat generating plant will not run on maximum capacity until years after its initial construction. Significant amounts of excess heat will be produced resulting in low project returns (Dockside Green, Vancity et al. 2007a).

A fair few of the renewable technologies that are to be installed are thought to be of demonstration purpose. Not focusing on more electricity production on site through various renewable technologies is something the development may be criticised for in the future. Moreover, both the sewage plant and the biomass plant cannot be evaluated under the LEED certification due to limitations of the program (Dockside Green, Vancity et al. 2007a). Since these implementations are two buildings that are of great importance to the site and will gain a lot of attention, it is unfortunate not to have them certified under the environmental building standards that otherwise apply.

Achievements

Actual achievements are difficult to measure to date, since the development is not yet operating. However, constant updates and predicted measurements show that the dwellings will operate as expected.

The Dockside Green are committed to providing an annual sustainability report on the progress of the stated triple bottom line goals which include successes, failures and new goals and challenges. The strong incorporation of the outlined triple bottom line is vital, constantly involving the interest of possible future residents, who are the ones that will retain the sustainability within the development. The commitment to the strategy is also shown in the Yearly Sustainability Report, in which the outline follows that of the Triple Bottom Line Approach.

A commitment by the Dockside Green partners throughout the project has been the emphasis on local developers of the technology used on site both after and during construction. To involve and support companies around the new development a positive attitude towards the project may develop.

7.2.5 Conclusions

Since the Dockside Green project is estimated to be finished for residents to move in during 2009 it cannot yet be determined if the project will result in a greenhouse gas neutral or positive development. This project does however take a step further in terms of environmental implementations both accounting for the greenhouse gases released during construction. So far the yearly reviews shows that the implementations of the project is in line with the outlined goals (Dockside Green, Vancity et al. 2007a), which is an indicator on that it will be a successful outcome. Similarly to the BedZED development, an implementation such as the Dockside Green is vital for future sustainable development. The strong focus on the Triple Bottom Line aims at, and hopefully will, enable the development not to sacrifice any comfort or increase costs making the development open for a mix of residents.

7.3 CASE STUDY 3- Västra Hamnen in Malmö, Bo01

7.3.1 Project Description

The development of Västra Hamnen was initiated when the decision was made that Malmö was to host the European Housing Exhibition in 2001 (Rosenberg 2002). The area specifically developed for the exhibition was named Bo01 and is characterised by architectural multitude and have been visited by people from all over the world. The area around it, referred to as Västra Hamnen, continues to develop and evolve with new residential and commercial buildings. The whole area covers around 175 ha (Dalman 2008) and is planned to house about 10,000 people and 20,000 employees (City.of.Malmö 2003). Additional areas have developed in Västra Hamnen since the initiation of Bo01 such as Dockan, Flagghusen and Fullrigaren, Universitetsholmen, Varvstaden, Mellersta Västra Hamnen (the Mid Western Harbour), Västra Hamnporten (the Western Harbour Gateway), Teknikportalen (the Technique Portal), Hamnparken (the Harbour Park) (City of Malmö 2003) and the architectural landmark the Turning Torso. These neighbourhoods are currently in different phases of development. Västra Hamnen have a focus on three main objectives: Social, Ecological, and Economic Sustainability (City of Malmö Planning Office 2008).

The area of Bo01 is defined as a climate neutral city development, originally created as a demonstration project. The concept of the definition is based on 100% locally produced renewable energy from wind turbines, solar panels and geoenergy to provide all energy (City of Malmö Planning Office 2008). The development supplies excess energy when produced and extract energy when needed, aiming to be climate neutral over a one year basis. However, emissions are estimated on an operational basis only. There has not been an opportunity to provide for an equally climate neutral program for the further development of Västra Hamnen, but the strong focus on humans and the environment is still required to be present in all the new dwelling, commercial and educational projects. The aim is, with Bo01 as an initiator, to make Västra Hamnen an international leading example of a densely populated area, with an environmentally focused neighbourhood. The district shall inspire creativity, develop knowledge and also stimulate economic growth.

Due to Bo01 being the climate neutral development and similar to the defined zero emission development, the main focus of this case study will be on Bo01.

7.3.2 Background

The area around Västra Hamnen used to be a heavily industrialised area. From the mid 60’s until the late 70’s, the largest dock in the world was built along with a gantry crane, by a company called Kockums. The Kockums crane became a landmark for Malmö city, present long after the fall of the company. After the shipping epoch, SAAB-Scania took over the area with one of the world's most modern car industries. Kockums was still present in the area at this time, with a new focus and with great success in export of submarines to, for example, Australia. Today, Malmö is still the major location for Kockums, but with an emphasis on education and development, in collaboration with different universities. The production is based on wind turbines, trains and lego (Rosenberg 2002).

Through the European Housing Exhibition and the development of Bo01, the initial and extremely important steps were taken towards transforming the area into a residential housing district, today referred to as Västra Hamnen and all its interactive developments.

There are five goals for sustainability set out for Västra Hamnen (City of Malmö Planning Office 2008);

» A NATIONAL EXAMPLE OF SUSTAINABLE CITY PLANNING

With the international attention due to the exhibition, a vital part of the development, and especially Bo01, was to show the benefits of sustainable development principles.

» KNOWLEDGE CITY

Västra Hamnen is an important part of a project in Malmö City towards a knowledge city. To enable knowledge to spread, the interaction between humans and the development is crucial.

» MEETING PLACES

The goal is to build inspirational meeting places, where people with different ideas, knowledge and experiences can interact with each other.

» THE MIXED CITY

A mixed function area is desired, where people can live, work and socialise. This results in a development involving dwellings, commercial buildings, workplaces, shops and restaurants.

» SURPRISES AND ATTRACTIVENESS

Delivering surprises to the people interacting within the area aims to encourage more discoveries of the qualities of the development.

7.3.3 Bo01

Bo01, or the City of Tomorrow, is said to be a construction in a brownfield, being the former industrial harbour. Being a project based on the European Housing Exhibition it was sponsored by the EU and also had a wide range of actors involved. Some of the actors were: the city of Malmö; National Board of Housing; Building and Planning; the Ministry of Environment; the Swedish Government; EU; E.ON Sverige AB (private energy supplier); Lund University; and various other developers (Malmö Stad 2007). Bo01, including Turning Torso, takes up 25 ha providing housing for around 2400 people in some 1600 apartments (Dalman 2008). The goal of being a climate neutral city development is aimed to go hand in hand with diverse architecture and exiting development to create a sustainability concept for the whole area and it has already received a lot of international attention.

Ecological, Economic and Social Sustainability

Based on the five goals set out for all of Västra Hamnen, some concrete goals for sustainable city development were created. Even if the developers do not work on a triple bottom line principle, the set up is fairly similar. Based on the aim to serve as a national and international example of sustainable living, goals for Social, Ecological and Economic Sustainability was created. The goals apply to the whole development and hence they do not apply to climate neutral developments, but is one step in the right direction towards a more sustainable living.

Ecological Sustainability goals involve targets for the amount and type of energy used targets, the use of renewable materials for construction, waste targets and creation of biodiversity. Parts of the *Economic Sustainability* goals were to introduce variety in the development to provide robustness. Moreover, higher initial costs are to be invested in long term sustainability buildings, with longer life span and hopefully lower maintenance costs and also a reasonable cost of living in the area is strived for. In terms of *Social Sustainability* meeting places is a vital point, enabling exchanges between people with different backgrounds, knowledge and cultures. Focus is also on planning for people with disabilities and to create a safe area to live in (City of Malmö Planning Office 2008).

7.3.4 Sustainable Technologies and Construction

The initial challenges when creating Bo01 was the examination of the earlier hardly industrialised ground. A volume of 6000m^3 had to be taken away for decontamination before construction could commence. As the area was planned a strong focus was on making a sustainable city that at the same time was attractive, where sustainability came as a bonus to the houses that people wanted to buy. There was no general approach taken to construct the dwellings and the commercial buildings, instead twenty two different architects, given a lot of freedom, were involved in designing different houses within the area (City of Malmö 2003).

Green areas and Green Buildings

Since many different architectures developed different houses on the area of Bo01, there is no one principle design used. Instead there were certain measures set for ecological sustainability and an energy efficient building approach was required where a low energy use of 105 kWh/m^2 and year was the maximum allowed use (City of Malmö 2003). A wide range of different approaches were taken to manage the sustainability standards. Some houses are equipped with complicated technologies whereas others have simpler solutions to reach the goals, all being part of the demonstration purpose of the development (City of Malmö 2003). A returning feature throughout the development is all the houses being built really close together, both saving energy and enabling an efficient use of ground space.

Renewable Goals and Technologies

The initial infrastructure plan was to achieve 100% local renewable energy. Electricity comes mainly from wind power and to a limited extent from solar PV. Heat is supplied from biogas, locally produced from sewerage, heat pumps from aquifers and seawater and solar collectors (Hancock 2001). However, the grid is used to balance the use so the climate neutral goal is achieved over one year.

Below sketch shows an outline of the technologies used:

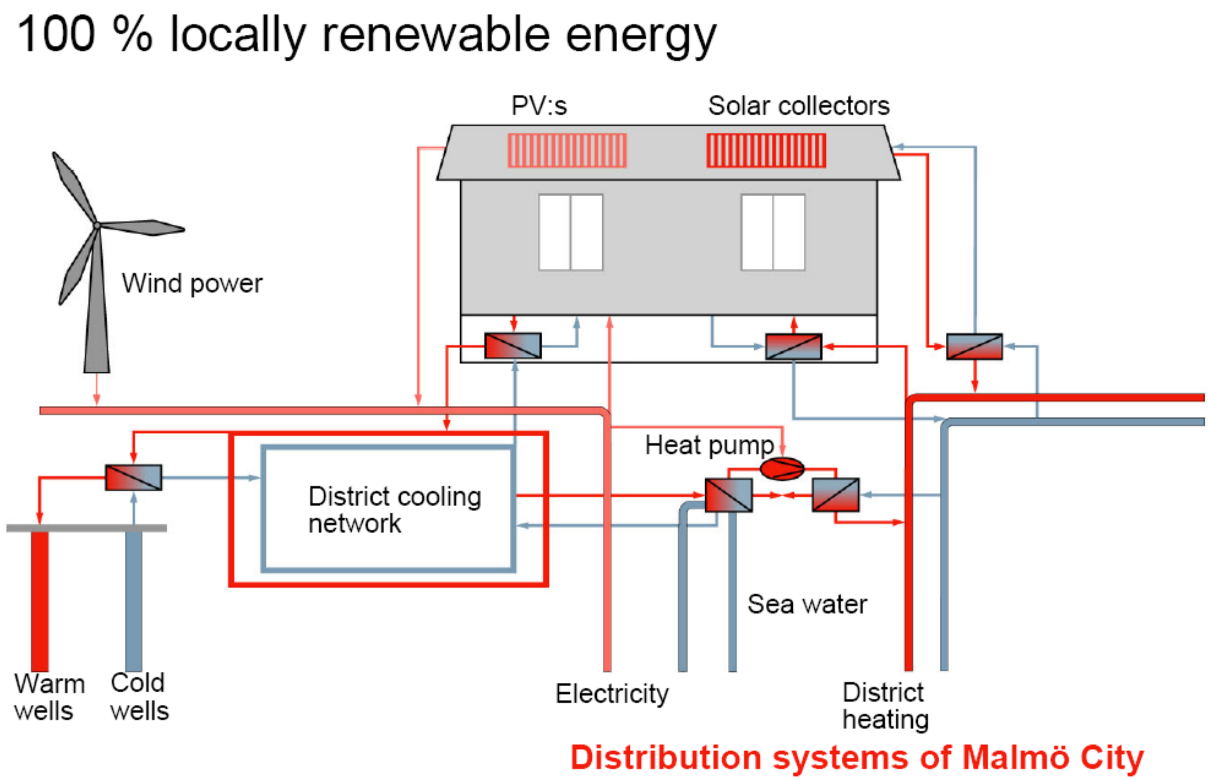

Figure 15: Energy distribution in the Bo01 area (EON 2007)

The biogas is produced from the residents own waste. There are two different systems implemented for waste collection. One is underground vacuum tubes, one for food waste and one for dry waste. Where the residents dispose of their waste in closely located recycle stations. The other option is waste mills for food waste placed in the sink in the kitchen (VA-Verket 2005). From the food waste, biogas consisting of methane and carbon dioxide is produced. A biogas reactor converts the organic waste into fertiliser and biogas, returning the gas back to the apartments via the gas main (Hancock 2001) or is used as vehicle fuel (Roberts and Tham 2001). It is estimated to be able to generate 290 kWh/year for each Bo01 resident (Hancock 2001).

The large heating need is partly covered by heat pumps extracting heat from aquifers and seawater, with a system consisting of 10 wells on a depth of 90 meters. This allows for seasonal storage for heating and cooling and is spread throughout the development via district heating and cooling systems (EON 2007).

Additional heating is received from 1400 m^2 of solar collectors placed on top of a few of the buildings in Bo01. Of these, 200 m^2 are vacuum collectors and the rest are flat plate collectors. In total, it is estimated that they produce 500 MWh every year (City of Malmö 2003).

For the electricity supply a 2MW wind turbine is installed along with PV cells covering about 120m^2 (City of Malmö 2003). The wind turbine supplies about 99% of the electricity and the PV only 1% (EON 2007). These supply electricity to the apartments, the heat pump, fans and other pumps in the area.

Water management

Water management is not developed as far as the other aspects of Bo01. The runoff of rainwater is controlled by locally by green roofs and with canals discharging it into the sea. Waste water is not treated on the site and is treated in the city's purification post (Hancock 2001).

Traffic Plan

The area within Bo01 is car free and parking is limited. When in need for a car, a pool of electric vehicles are available for residents to use for travel to the city. Alternative fuel from the biogas plant or renewable electricity from wind power is available for residents with those types of cars (Hancock 2001).

Even if the use of cars is made available, the focus on alternative transportation is stronger. Cycle traffic is the most important element in the transportation plan, and the cycle paths are made to be an attractive alternative to shorter journeys (Roberts and Tham 2001).

7.3.5 Discussion

Issues

Even if the goal was that each building was to use a maximum of 105 kWh/m^2 and year, this was not achieved in all buildings. Rather, the average heating and electric requirements were 120-150 kWh/ m^2 and year (Malmö Stad 2007), making it harder to achieve the climate neutral goal since the electricity production was based on such restriction. However, the best achiever in energy efficient use of electricity was as low as 87 kWh/ m^2 and year, indicating that the different designed houses as well as people's energy behaviour play an important role.

Even though the waste management is a great plan in theory, there have been numerous issues with the recycling methods. The waste mill in the kitchen has shown to be more effective in terms of getting pure food waste for biogas production due to that it stops working if people attempt to mill materials that are not meant to go in. The pureness of the food waste in the vacuum system is around 90%, which is considered reasonable. However, the biggest issue is that at evaluation time, only about between 28-46 weights percent of the food waste is actually recycled. It is believed that the lack of recycling depends on lack of education and information. Different attempts have been made to involve people in the sustainability process, but they have not always been very successful (VA-Verket 2005).

There have also been several issues with the emptying of the dry waste vacuum systems in the Bo01 area. Firstly the company have had problems with clogged up pipes, not enabling them to empty the stations, and creating problems for the residents with an overfull system where they cannot dispose of their garbage. Another issue as far as environmental sustainability is concerned is that the vehicles used for the emptying of the dry waste station run on diesel, compared to the rest of Malmö's waste trucks which run on natural gas. One of the reasons for this is the large amount of power needed to suck out the garbage, where diesel has that potential. However, this is not a great decision when trying to promote alternative transportation within the development.

Achievements

The strategic placement of Bo01 in Västra Hamnen enabled easy access for international and especially European attention. It is in the third largest city of Sweden, but located in the centre of the Öresund region with good communication possibilities in many directions. Malmö is a city of change and have during the last ten years become a very multicultural city with 160 different nationalities and 100 different languages spoken. In line with this, the Bo01 project has helped the city move away from a traditionally industrial city, towards a sustainable city with international influences.

Calculations show that the investment in Bo01 was a financial loss. However, the calculations also say that further investment in a sustainable development of Västra Hamnen will be beneficial. Different approaches are taken, in terms of time for development and costs connected, and the profit is estimated to be between 2 and 25 million Swedish Kronor (about $340,000- 4,300,000) (Rosenberg 2005).

A part of the set goals for Bo01 involved the intention to create an international example of sustainability. Being a part of the European Housing Exhibition, Bo01 has received a lot of attention and worked as a model or example in other developments.

7.3.6 Conclusion

Calculations may show a future benefit for the project, but at the same time the budget may once more burst as it did with Bo01. However, the total benefits of a project like this have to be accounted for. Considering one of the aims of the project was to show the benefits of sustainable development principles, Bo01 has definitely made an impression. It has attracted great international attention, and is for example used as measurement when developing the Dockside Green.

Bo01 has definitely managed to become a demonstration project in sustainable living. The intention was to show different ways of achieving a sustainable goal, which was done by including different architects and housing designs, two newly developed waste management systems and a wide range of partners. Even if some houses and especially one of the waste systems have shown not to live up to expected goals, such knowledge is vital for continuing development. Seeing Bo01 was an early project in its field, the intention to try many different options to sustainability was a reasonable approach.

7.4 Overview

Table 13: Comparison between the case studies

	BedZED	**Dockside Green**	**Bo01**
Aim	Zero (fossil) Energy Development -Operational net zero for stationary energy use over a one year period -Reduction in emissions from energy sectors such as water, waste, transport and materials	Greenhouse gas neutral development -Life cycle net zero for stationary energy use - Highly emphasised implementation of strategies which will reduce emissions in other energy sectors	100% locally produced renewable energy -Operational net zero for stationary energy use over a one year period -Producing all energy onsite -Reduction in emissions from other energy sectors
Site	Brownfield	Previously contaminated brownfield	Previously heavy industrialised brownfield
Area (ha)	1.7	6.05	25
Ready	2002	2009	2001
Dwellings/inhabitants	82/220	1100/2200	1600/2400
Triple bottom line	Yes	Yes	No Environmental, Social and Economic Sustainability
Building energy	-Aimed for low embodied energy -Reclaimed, recycled and local material used	-Planned biomass heat generating plant to support the construction to be life cycle net zero	-Low embodied energy

Passive design	Passiv Haus	Passive design to match LEED requirements	A wide range of different solutions to passive design
Energy efficiency measures	-20-30% lower energy use for the construction process -56% lower energy use in dwellings		
Biomass energy	-CHP run on biogas produced from local wood chip waste. -130 kW_e output	-Biomass heat generation	-Biogas produced from inhabitants own food waste
Wind energy	As demonstration	As demonstration	2 MW
PV	777 m^2	As demonstration	120 m^2
Solar thermal		As demonstration (for example solar hot water demonstration)	1400 m^2
Water	-Biofiltration system to produce grey water for toilets etc. -Water efficiency is included in housing design, otherwise	-Sewage treatment and water re-use program onsite to provide water for gardens, toilets and green-roofs.	Water is run through the local system, no additional installations sewerage system is installed
Transportation plan	-Green Energy Transportation Plan -PV powered electric cars -Reducing need to travel -Reducing impact of the cars used -Promoting alternatives	-Alternative Transport Strategies -Walkway and bike trails -Local car share -Car parks sold separate to houses -Bike parking provided	Traffic Plan -Electric vehicle car pool for residents -Alternative fuel from biogas plant -Focus on alternative transportation

8 Discussion

As mentioned at the start of this thesis, it is vital to document the progress of zero emission developments in order to continue to expand and promote the concept of those developments. This is crucial due to the potential that these developments have to set an example to the rest of the world, showing the future possibilities to create developments which release zero emissions, as a part of the actions required to tackle climate change. In this chapter, the important steps in an establishment phase will be recapped, and the importance that these developments have now, and how they can expand in the future will be discussed.

As outlined, important milestones in the implementation and establishment of zero emission developments are:

- ✓ Defining what the proposed development will involve.
- ✓ Prepare an energy assessment of the future development.
- ✓ Consider possible renewable energy sources and technologies, energy efficient technologies and abatement strategies.
- ✓ Work through a well integrated approach involving social, economic and environmental sustainability to provide a successful strategy.
- ✓ Involve national policies and well established evaluation methods.
- ✓ Create several possible scenarios for the proposed development to determine the most suitable for the particular location.

Each of these milestones has been discussed and suggestions of possible definitions, technologies, strategies and scenarios have been made. These guidelines are significant in defining the necessary steps required when implementing zero emission developments, hence also central in future aims to reduce greenhouse gas emissions internationally. Below the importance of zero emission developments will be discussed along with future prospects.

8.1 Zero Emission Developments Today

Along the lines of the definition of this thesis, zero emissions often refer to the operational stationary energy use. Buildings today are generally responsible for about 40% of the energy use in a country (Schmidt 2009) and they are some of the easiest emissions to measure and estimate. However, both embodied energy in construction and additional energy sectors could be considered. Strategies and energy efficient technologies could be used to decrease the emission in those sectors. Hence zero emissions for those fields may not be achieved, but there may be a considerable decrease in emissions.

The earlier presented triangle can be used to visualise a situation where operational stationary energy is aimed to produce zero net emissions, but where other strategies may be used to decrease emissions from a life cycle perspective or for additional energy sectors:

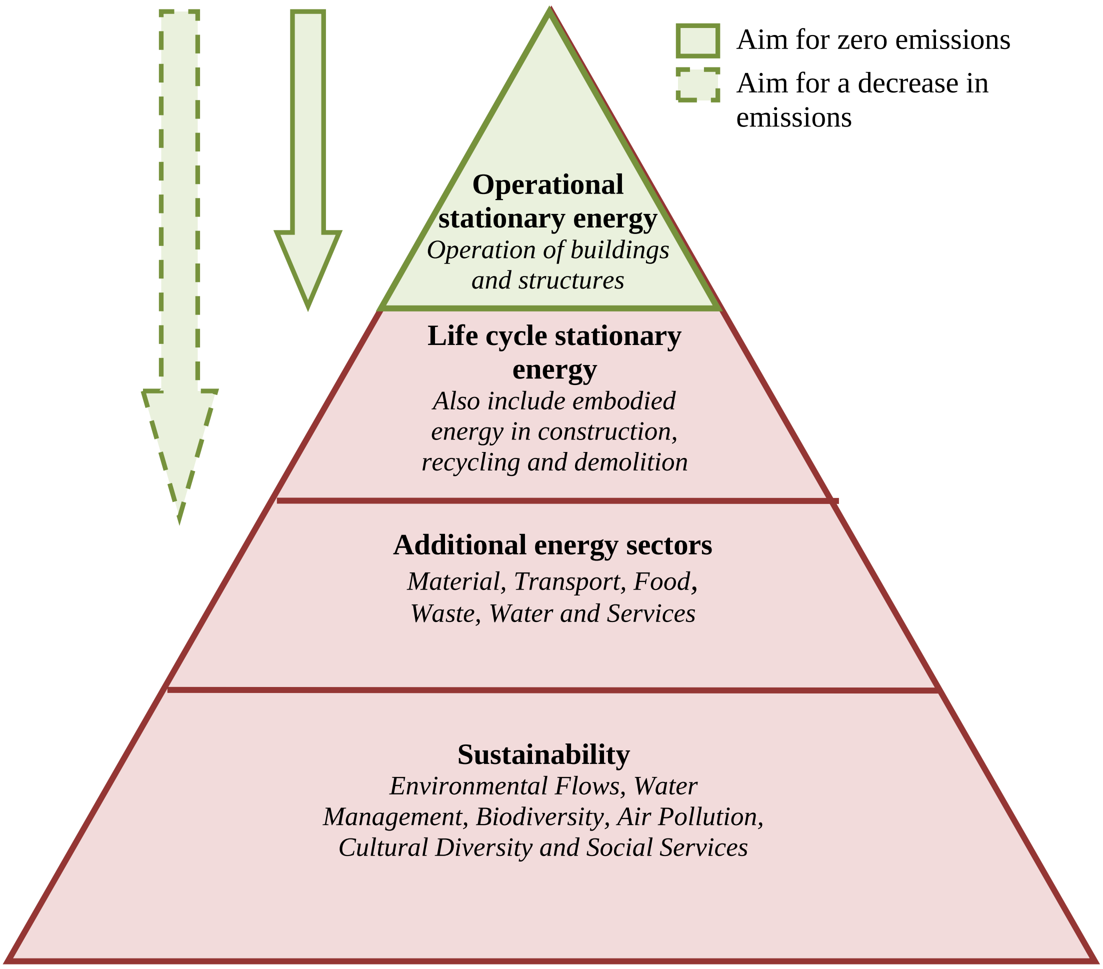

Figure 16: Zero emission developments today

The arrows represent the above discussed inclusion of emissions, being zero from an operational stationary energy point of view, but using other technologies and strategies to reduce emissions from the life cycle of the operational stationary energy and from additional energy sectors. Being zero emissions in operational stationary energy is an important step towards reducing greenhouse gas emissions and, the incorporation of decreasing emissions in additional energy sectors will result in increased knowledge on suitable solutions for such reductions, so that in the future, emissions from these sectors can be pushed towards zero.

The increasing understanding of how to create a zero emission development from an operational stationary energy point of view, and the importance of involving an extended group of energy sectors and life cycle analysis shows a positive progress for similar projects.

Creating developments from a sustainable perspective involves much more than just trying to decrease emissions. Living sustainably is about living within the means of our natural systems and ensuring that our lifestyle has no harm on our society and cultures. There are obviously many ways of defining sustainability, demonstrating the importance of each development defining what sustainability means to, and how it can be achieved in that particular development.

An initiation of a movement down the triangle is aimed for, to provide positive outlooks for increasingly sustainable zero emission developments. Hence considering zero emissions for operational stationary energy is a good initial approach to zero emission developments, establishing a baseline to build on for future, more expanded definitions.

8.2 Future Possibilities

As for the future of zero emission developments the initial aim should be to involve life cycle stationary energy, additional energy sectors and also the life cycle of these. When methods for such developments are well established, being zero emissions could instead become one part of a much broader sustainability concept of how we build on and utilise our land. The future aim for zero emissions and the involvement of zero emissions into sustainability is shown in figure 17:

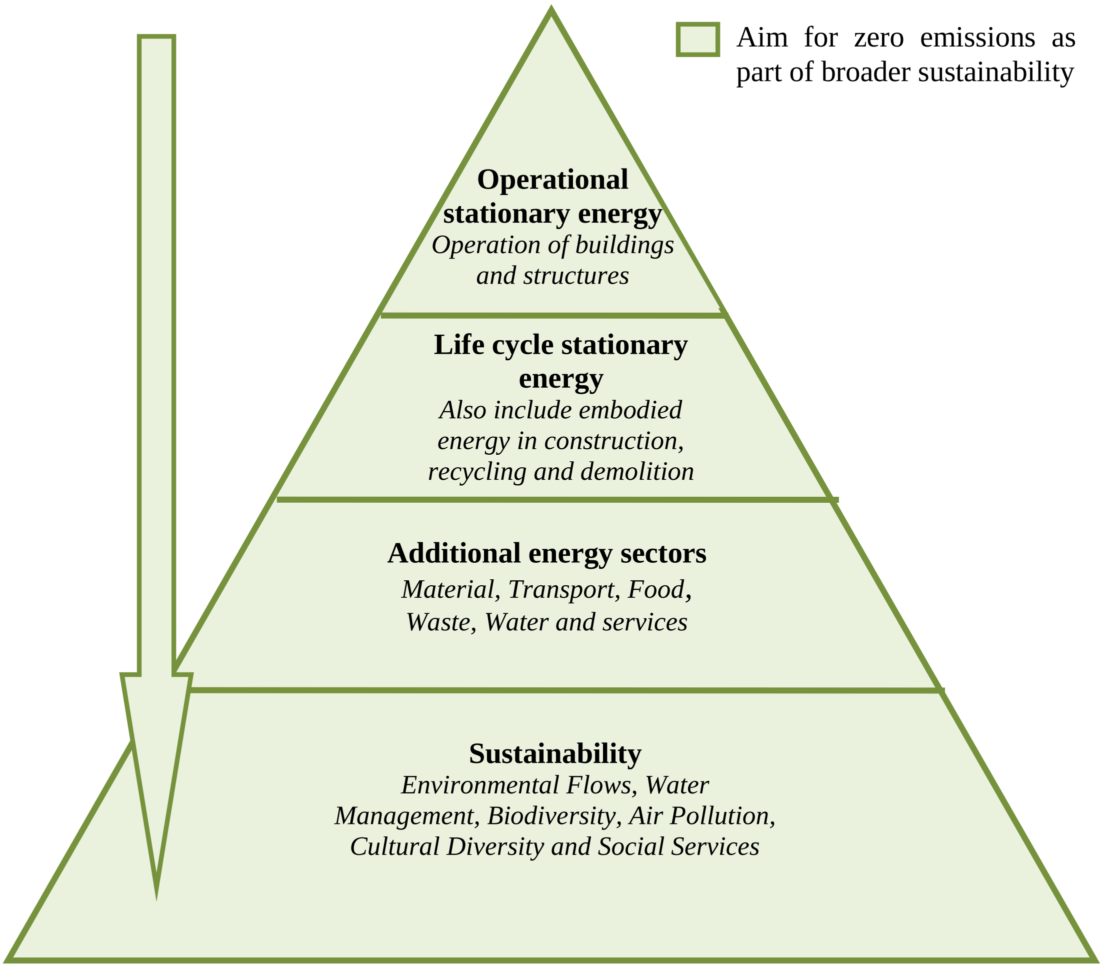

Figure 17: Zero emission developments in the future

The zero emission developments that exist today generally cover relatively small areas. Increasing the size of these types of developments is one future aim to consider. If greater areas are introduced, work across city, state and maybe even international borders, is required. For a zero emission approach to be established on a national level in many countries, or on an international level, appears a long way off. However, that should be an aim for the long term future.

There are possibilities that smaller precincts create boundary issues when quantifying and assigning emissions. For example, transport emissions in a very small area may be difficult to allocate since it has to be decided which emissions happening outside the precinct that should actually be assigned to the residents within the precinct. However, involving a larger area, such as a state, may instead allow for quantifications from petrol stations or similar, to give a more accurate estimate of the total emissions from transport within that area.

Particularly with improved establishment of governmental policies, the measurements of emissions from transport, food and waste may be less complicated due to increased accessibility to vital data. Since planning on such large scale is also part of governmental responsibility, and for that to be carried out with a zero emission development approach, it obviously requires very strong environmental commitment by the government and other involved bodies. Similarly, actions taken to reduce or eliminate the emissions for those energy sectors may benefit from being less locally controlled.

As more polices, rules and regulations are developed on local, national and international levels to enable for work to decrease emissions and impact on climate change, implementations such as zero emission developments will hopefully be made easier. It is however important not to wait for that time to come, and instead to react now to speed up the process of implementation of policies, rules and regulations.

Current implementations of zero emission developments still require a private financier or company, along with governmental or other funding instead of being part of national policies. However developers are working with the tools and equipment which are today available and hopefully we will look back at these developments and see how they were the base for future bigger city, state or national implementations.

Larger implementations in terms of areas and borders, boundary conditions and timeframes involve greater extent of planning and definitions, and will not be possible until a good understanding of zero emission developments is established. Due to this fact smaller implementations are vital for future possible large zero emission developments. These developments act as examples of how well implemented sustainable living can be carried out to promote a future moving towards developments devoted to larger areas, greater involvement of energy sector and over extended timeframes.

8.3 Importance of Zero Emission Developments

It is presently important to push for stronger commitment on local, national and international levels to decrease greenhouse gas emissions and act on climate change. Zero emission developments are an excellent way to do so, showing it is possible to live sustainably without sacrificing the comfort of people or their social environment.

Nevertheless, there are always risks involved with new innovative developments. Initially there are risks involved in establishing feasible technology combinations. Issues with grid connection and the control of feeding and extracting electricity depending on the performance of the renewable technologies at the time are possible risks. In spite of this, as zero emission developments are more broadly recognised, issues with connection of distributed energy sources to the grid are likely to decrease.

An existing lack of confidence, by investors, in innovative projects and an often high initial cost may hold back what could otherwise be a fast growing market for zero emission developments. It can be argued that those types of risks are perceived rather than real. This is particularly evident in the NPV calculations involving a future carbon price, where a renewable energy technology scenario shows to be the most economically feasible one. To overcome such problems, already established zero emission developments needs to be well promoted. Similarly, many of the discussed renewable energy technologies and strategies a reliable and this message have to be properly presented to possible future developers or project proponents.

In any developing sector involving new technology, new attitudes and ways of implementation, there are going to be obstacles and impediments. Focusing on overcoming these will make zero emission developments an important action towards reducing greenhouse gases and have a positive impact on global warming.

Despite the fact that there is an enormous environmental benefit from these projects other achievements can also be seen. The additional benefits expected for different actors involved are: the extensive attention gained from the result of being a pilot project; the research and development they embody; the improvement in skills and knowledge around renewable energy technology and sustainability; and the image of having an environmental approach in times when climate change is an international concern.

Moreover, early implementations demonstrate examples of established and new renewable technologies available to reach the targets of the development. Increased exposure of functioning renewable technologies to the public should result in greater acceptance which should also push the development of these technologies. Also, increasing investment in renewable technologies will most likely result in decreasing investment and running costs.

In summary, early zero emission developments provide the guidance towards extended implementations. This is particularly demonstrated through the outline of the defined zero emission development of this thesis, and also the consideration taken to additional energy sectors in the performed case studies, demonstrating the required initial steps towards a more developed future approach. In the future the hope is that these early developments will play a vital role as a guideline to larger and more complex definitions and implementations of zero emission developments.

9 Conclusion

The definition of a zero emission development is a vital but complex process. It is argued that no universal definition should be developed due to the variable conditions and opportunities each development has. It is instead crucial to each development to create an individual definition. An outline involving what is important to consider when defining a zero emission development has been created to guide developers when establishing *their* definition. A definition should involve an establishment of suitable *terminology* and clarification of what the terminology involves. Moreover, an *area*, *boundary conditions*, classifying involved energy sectors, and *timeframes* for the emissions accounted for, are crucial elements of a definition.

Similarly, suitable technologies should be evaluated for each individual development. This is to be done through an initial energy assessment, an evaluation of available renewable energy technologies, energy efficient technologies and abatement strategies, followed by modelling of possible scenarios of technology and strategy combinations. Appropriate renewable and efficient energy technologies and abatement strategies are solar and wind energy, hydroelectric energy, co and tri-generation, ground source heat pumps, passive housing design and retrofitting of existing buildings, and different types of carbon offsetting. The more scenarios that are then modelled, with different proposed technologies and strategies, the more likely the project proponents are to find a model which suits the aims and objectives of the particular development. It is stated that the modelling of only four scenarios is not sufficient when choosing the optimum combination. Instead the purpose of the four scenarios modelled in this thesis is to provide a spectrum of possible combinations of technologies and strategies, varying from scenarios with more established energy efficient technologies to those completely relying on renewable energy technologies, depending on the main aims and objectives of the project proponent.

Well established technologies that are seen in the scenario modelling are wind energy, different types of solar energy and co-generation. There are both risks and issues involved with these technologies, but similarly they all have good benefits. Some key findings from creating different scenarios have been that co-generation is a good alternative in zero emission developments due to its efficient production of larger amounts of both heat and electricity. Moreover, wind energy supplies sufficient amounts of electricity in a location where the wind conditions are good. However, extensive research is required before implementation. Solar energy, particularly solar heating, is suitable for hot water heating. PV panels are also important in zero emission developments. They are not yet capable of supplying all electricity, due to costs and also space. It is instead most suitable to utilise PV cells to even out peak demand of electricity. This is particularly suitable in Australia where peak demand matches the time of solar PV output.

Using natural gas or importing energy requires the offsetting of emissions. How this is achieved all comes down to the definition of the development and how the set targets are to be reached. The combinations of technologies also impact on the initial and running costs of the development. Where solar and wind energy tend to be more expensive initially, co-generation has a higher annual running cost due to required fuel, personnel and maintenance. The co-generation costs are particularly variable when operating on biofuel, due to local availability, fuel security and type of fuel used. All costs and benefits for each scenario have to be closely evaluated and justified before implementation.

To properly implement the defined zero emission development and reach the set goals, the cooperation of the future inhabitants is essential. Hence all implementations should be viewed from a social and cultural perspective as well. To understand and solve environmental problems by involving human actions, their social dimensions are to be understood. Critical areas to consider when doing social research are the social and cultural structures which exists in the area and which of these can be harnessed and used to positively work for sustainability. This is particularly important in terms of the passive house design, which is commonly used, and do require the efforts of the resident to live up to the expected outcomes. As discussed, behavioural changes both in passive designed and retrofitted house plays a vital role in decreasing the energy demand. Social research and consideration will more than likely result in stronger efforts from the residents to work with the sustainable outline of the development, and developers are more likely to reach a target for zero emissions.

In addition, economic sustainability is obviously vital. The difference between zero emission developments and regular housing developments should be recognised. It is easy to set economic barriers which work against sustainable development instead of realising the decrease in costs involved with reducing the impact on the environment. A new costing approach needs to be taken on by these developers, realising that increasing costs in certain areas will decrease costs in other. Considering the carbon price, based on the Garnaut-25 scenario, will increase around 400% in 2050 compared to 2010, the earlier much higher costs for solar and wind technologies may not be as significant any longer. Under this development, the demand for biofuels may rise, and both increase the running costs and decrease the fuel security for a biofuelled co-generation plant. Again, an establishment involving hopefully further developed large solar and wind energy technologies can be an attractive choice.

A cost and benefit analysis of the four scenarios has also been performed. It demonstrates a quite large investment cost for large implementations of wind and solar energy. However, a scenario fully dependent on a renewable energy technology, through the running of a biofuelled co-generation plant, shows to be economically justifiable. This is particularly present when a NPV, including a future increasing carbon price, is calculated for the different scenarios. The biofuelled co-generation then showed to be the most feasible investment.

Such observation illustrates the importance of noticing the great impact an estimated carbon price actually has on the economic benefits on zero emission developments. There are still other economic benefits raising form environmental benefits, which are not calculated in the cost analysis, but that can have an additional positive effect on the NPV for the scenarios more dependent on renewable energy technologies, rather than energy efficient technologies. For future implementations, and to justify high initial costs for zero emission developments, a price on environmental benefits could be very important to consider. The scenario heavily dependent on renewable wind and solar technologies is still much more expensive, but there is a possibility that those costs will decrease with increasing knowledge and larger production of both solar and wind technologies. The NPV sensitivity analysis stresses the importance of including future probable costs for emissions.

In summary, it is shown that the establishment of zero emission developments should be dependent on a clear definition, an energy assessment, an evaluation of renewable and efficient energy technologies as well as good abatement strategies, and the modelling of different scenarios. Moreover, sustainability has to be implemented through an integrated approach involving cultural and social aspects and economic sustainability. It is also evident that the inclusion of future costs on carbon will have a strong impact when justifying the implementation of zero emission developments. Additionally, the significance of considering a price on environmental benefits is stressed. Current implementations of zero emission developments play a vital role as a guideline to larger and more complex definitions and establishments of zero emission developments. It involves a wide range of stakeholders and all of those need to cooperate to enable for zero emission developments to increase in scale, quantity and targets aimed for. This is important so that in the future it is ensured that creating zero emission developments is a part of a larger and more complex aim for sustainability.

In conclusion, as zero emission developments represent a small-scale application of what hopefully will be the future of all new developments; they establish a learning process for further spreading of implementations, definitions and renewable and efficient energy technologies and abatement strategies. Documentation and guidelines of these early developments are vital to support increasing amount of establishments, and provide an important stepping stone towards a future of more sustainable living.

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Appendix 1-Calculations

For all Scenarios

Table 14: Assumed energy output

Total hot water heating, heating/cooling	**4,158**	**MWh/year**	**36% of the total use**	**5,000 MWh/year**
Total electricity demand	**7,392**	**MWh/year**	**64% of the total use**	**8,000 MWh/year**

Scenario 1

Table 15: Approximate costs for natural gas fired co-generation (Lazzarin and Noro 2006; EIA 2008; Strasa Konsultanti SIA 2008; Sanderson 2009)

Gas fired co-generation plant			**Comments**
Electricity use	8,000	MWh_e/year	
Operating hours	20	h/day	
	7,300	h/year	
Engine requirement	1.10	MW	
Reciprocating engine efficiency	0.325	(average)	
Engine required	3.37	MW	
	3,372	kW	
Heat generation	16,000	MWh/year	2 units heat to 1 unit electricity
Operating hours	20	h/day	
	7,300	h/year	
Heat energy use	5,000	MWh/year	
Excess heat	11,000	MWh/year	
Plant investment cost	650	€/kWe	1 € = $1.97323
	1,283	$/kWe	
	4,324,888	**$**	
Heat network investment cost	550	€/m	
	1,085	$/m	
Length of pipes	3,000	m	
Total network cost	**3,255,830**	**$**	
Total installation cost	**7,580,717**	**$**	
Cost natural gas Australia	4.5	$/GJ	
	0.016	$/kWh	
Annual fuel cost Australia	**398,450**	**$/year**	
Cost natural gas Europe	0.051	$/kWh	
Annual fuel cost Europe	**1,262,650**	**$/year**	
Maintenance cost	0.0103	€/kWh_e	
	0.0204	$/$kWh_e$	
Total maintenance cost	**163,068**	**$**	
Total annual cost Australia	**561,518**	**$/year**	

Table 16: Approximate emissions and offset costs (Australian Government 2008b; EPA and RMIT University 2009)

Emissions released		
Emissions burning natural gas	57.30	kg CO_{2-e}/GJ
	0.21	kg CO_{2-e}/kWh
	0.21	tonne CO_{2-e}/MWh
Emissions gas fired co-generation	5,074	tonnes/year
Total Emissions	**5,074**	**tonnes/year**

As mentioned, approximately 30% of reduction in emission when retrofitting a home is related to behavioural changes. These estimations are accounted for when retrofitting the precinct. Below are the savings through both behavioural changes and retrofits showed, together with the emissions saved. It is then estimated how much such retrofit would cost in each building, and how many emissions are saved. Hence the total retrofit cost can be calculated.

Table 17: Emissions saved on behavioural changes (Bertsch 2009)

Emission savings through behavioural changes		
Switch off lights in rooms not being used	190	kg CO_{2e}/year
Switch off appliances at the power point when not in use	390	kg CO_{2e}/year
Take 4 minute shower instead of 7 minute shower - savings per person	110	kg CO_{2e}/year
Take 4 minute shower instead of 7 minute shower - 4 people do it	440	kg CO_{2e}/year
Wash clothes in cold water instead of warm - average household	130	kg CO_{2e}/year
Lower heater thermostat by 2^{o}C - central heating	890	kg CO_{2e}/year
Close off areas that don't need heating	360	kg CO_{2e}/year
Total emissions savings	**2,400**	**kg CO_{2e}/year**
	2.4	**tonnes CO_{2e}/year**

Table 18: Emissions saved through retrofitting homes (Bertsch 2009)

Emission savings through retrofitting		
Replace refrigeration	1000	kg CO_{2e}/year
Replace incandescent globes with compact fluorescent lights	155	kg CO_{2e}/year globe
10 lights	1550	kg CO_{2e}/year
Flow restrictors and aerators in taps	245	kg CO_{2e}/year
Install bulk insulation R=3.5	1250	kg CO_{2e}/year
Replace shower head	671	kg CO_{2e}/year
Total emissions savings	**4716**	**kg CO_{2e}/year**
	4.7	**tonnes CO_{2e}/year**

Table 19: Cost retrofitting (Murdoch University 2000; Environmentshop 2005a; Environmentshop 2005b; Environmentshop 2005c; Energymatters 2009d)

Costs retrofitting		
Internal door-bottom seal	6.8	$/door
Cost bottom seal	13.5	$
Sealing	0.86	$/m
Cost door sealing	12	$
Window sealing	0.52	$/m
Cost window sealing	19	$
Draught seeling (2 doors, 6 windows)	44	$
Replace incandescent globes with compact fluorescent lights	30	$/globe
10 lights	300	$
Flow restrictors and aerorator taps	10	$/restrictor
Cost restrictors and aerorators	30	$
Efficient shower head	50	$
R=3.5 insulation	310	$/30m^2
For house insulation	1,095	$
New fridge	1,700	$
Total	**3,219**	**$**

Table 20: Door and window assumptions

6 windows á 6 meters circumference	36	m
2 doors á 7 meters circumference	14	m
House 9x9 m		
Roof on 40^o angle		
Insulation needed for the roof	106	m^2

Table 21: Total costs retrofitting homes (Desmedt, Vekemans et al. 2009)

Retrofitting Homes		
Emissions to offset from gas fired co-generation	5,074	tonnes CO_{2e}
Offset through behaviour change (aprox 30%)	2.4	tonnes $CO2_e$
Offset through new implementations (aprox 70%)	4.7	tonnes $CO2_e$
Total emissions savings	**7.12**	**tonnes CO_{2e}/year**
Houses to retrofit	713	houses
Costs per house	3,219	$/house
Total offsetting costs through retrofitting	**2,295,394**	**$**

Table 22: Approximate costs Scenario 1

Scenario 1		
Gas fired co-generation, precinct energy efficiency		
Total investment cost co-generation	7,580,717	$
Total retrofitting cost	2,295,394	$
Total installation cost	**9,876,111**	**$**
Co-generation		
Annual fuel cost Australia	398,450	$
Annual fuel cost Europe	1,262,650	$
Annual maintenance cost	163,068	$
Retrofitting		
Total retrofitting cost	2,177,514	$
Total annual cost Australia	**561,518**	**$**

Scenario 2

Table 23: Approximate costs for natural gas fired co-generation (Lazzarin and Noro 2006; EIA 2008; Strasa Konsultanti SIA 2008; Sanderson 2009)

Natural gas fired co-generation plant		
Electricity use	8,000	MWh_e/year
Operating hours	20	h/day
	7,300	h/year
Engine requirement	1.10	MW
Reciprocating engine efficiency	0.325	(average)
Engine required	3.37	MW
	3,372	kW
Heat generation	16,000	MWh/year
Operating hours	20	h/day
	7,300	h/year
Heat energy use	5,000	MWh/year
Excess heat	11,000	MWh/year
Plant investment cost	650	€/kW_e
	1,283	$/$kW_e$
	4,324,888	**$**
Heat network investment cost	550	€/m
	1,085	$/m
Length of pipes	3,000	m
Total network cost	**3,255,830**	**$**
Total installation cost	**7,580,717**	**$**
Cost natural gas Australia	4.5	$/GJ
	0.016	$/kWh
Annual fuel cost Australia	**398,450**	**$**
Cost natural gas Europe	0.051	$/kWh
Annual fuel cost Europe	**1,262,650**	**$/year**
Maintenance cost	0.0103	€/kWh_e
	0.0204	$/$kWh_e$
Annual maintenance cost	**163,068**	**$**
Annual offsetting cost	**63,420**	**$**
Total annual cost	**624,938**	**$/year**

Table 24: Approximate emissions and offset costs (Australian Government 2008b; EPA and RMIT University 2009)

Emissions and offset costs		
Offset cost	12.5	$/ tonnes CO_{2e}
	57.3	kg CO_{2e}/GJ
	0.20612	kg CO_{2e}/kWh
	0.20612	tonne CO_{2e}/MWh
Emissions gas fired co-generation	5,074	tonne/year
Total emissions	**5,074**	**tonne/year**
Annual offsetting cost co-generation	63,420	$
Annual offset cost	**63,420**	**$**

Table 25: Approximate costs Scenario 2

Scenario 2		
Natural gas fired co-generation, payed offsetting		
Total installation cost co-generation plant	7,580,717	$
Total installation cost	**7,580,717**	**$**
Annual offsetting cost	**63,420**	**$**
Co-generation		
Annual fuel cost Australia	398,450	$
Annual fuel cost Europe	1,262,650	$
Annual maintenance cost	163,068	$
Annual offsetting cost	63,420	$
Total annual cost Australia	**624,938**	**$**

Scenario 3

Table 26: Approximate costs for biofuelled CHP (Lazzarin and Noro 2006; Strasa Konsultanti SIA 2008; Sanderson 2009)

Biofuelled Co-generation plant			**Comments**
Electricity use	8000	MWh_e/year	
Operating hours	20.00	h/day	
	7,300.00	h/year	
Engine requirement	1.10	MW	
Reciprocating engine efficiency	0.33	(average)	
Engine required	3.37	MW	
	3,372	kW	
Heat energy use	5,000	MWh/year	
Heat generation	16,000.00	MWh/year	2 units heat to 1 unit electricity
Operating hours	20	h/day	
	7,300	h/year	
Excess heat	11,000	MWh/year	
Plant investment cost	650	€/kWe	1€ = $1.97323
	1,283	$/kWe	
Total plant cost	**4,324,888**	**$**	
Heat network investment cost	550	€/m	
	1,085	$/m	
Length of pipes	3,000	m	
Total network cost	**3,255,830**	**$**	
Gasifier			
Operating hours	20	h/day	
	7,300	h/year	
Gasifier requirement	1.10	MW_e output	
Gasifier efficiency	0.75		
Gasifier required	1.46	MW_e output	
Cost of gasifier	1,500	$/kW_e	
	1,500,000	$/Mw_e	
Total cost of gasifier	**2,191,781**	**$**	
Total installation cost	**9,772,498**	**$**	
Maintenance cost	0.0103	€/kWh_e	
	0.0204	$/kWh_e	
Annual maintenance cost	**163,068**	**$/year**	
Wood chips in ICE (33% efficient)	1.4	tonne/produced MWh_e	
Cost woodchips	50.00	$/tonne	
Annual woodchip cost	**400,000**	**$**	
Total annual cost	**563,068**	**$**	

Table 27: Approximate costs Scenario 3

Scenario 3		
Biofuelled co-generation		
Total installation cost co-generation plant	9,772,498	$
Total installation cost	**9,772,498**	**$**
Co-generation		
Annual fuel cost	400,000	$
Annual maintenance cost	163,068	$
Total annual cost	**563,068**	**$**

Scenario 4

Table 28: Approximate costs for boiler (Lattner Boiler Company 2008; Strasa Konsultanti SIA 2008)

Energy from boiler		
Energy required	2,594	MWh/year
Operating hours	20	hours/day
	7,300	hours/year
Investment cost boiler	14,410	USD/15hp
	20,073	$/15hp
	1,338	$/hp
Boiler requirement	0.36	MW
Boiler needed	0.44	MW
	12	hp
Invest in a 15 hp boiler	**20,073**	**$**
Heat Network Investment Cost	550	€/m
	1,085	$/m
Length of pipes	3,000	m
Total network cost	**1,650,000**	**$**
Total investment cost	**1,670,073**	
Personnel Cost	37,000	€/ person and year
Total personnel cost	73,010	$/ person and year
Running cost (2 personnel)	**146,019**	**$**
Efficiency boiler	0.75	
Cost natural gas Australia	4.5	$/GJ
	0.016	$/kWh
Annual fuel cost Australia	**52,488**	**$**
Cost natural gas Europe	0.0513	$/kWh
Annual fuel cost Europe	**166,328**	**$**

Table 29: Approximate Wind Energy Costs (Energymatters 2009b)

Wind Energy		
Turbine peak output	15	kW
Annual output	**22,500**	**kWh/year**
Electricity from wind power	6,667	MWh/year
Turbines required	**297**	**turbines**
Wind installed	4,452	kW
Material Cost (total)	158,000	$/turbine set
	46,893,815	$
Maintenance Cost	Medium	
Total Cost	**46,893,815**	**$**

Table 30: Approximate Solar PV Costs (Shone, Stapleton et al. 2008; Energymatters 2009a; Energymatters 2009c)

Solar Energy (PV)			
Polycrystalline			
PV peak output	130	W/ 0.89 m^2	1 Module
	146	W/m^2	
Peak sunlight in Melbourne	3.15	hours	
Output	0.460	kWh/m2 and day	
Annual output	**168**	**kWh/m^2 and year**	
Electricity from solar	1,333	MWh/year	
Panels required	7,939	m^2	
	0.79	ha	
	8,921	modules	
Solar installed	1,160	kW	
Panels	12	$/peak W	
	1,685	$/$m^2$	
	13,380,835	$	
Mounting Equipment	100	$/module	
	892,056	$	
Maintenance cost	Low		
Total cost	**14,272,891**	**$**	

Table 31: Approximate Emission and Offset Costs (Australian Government 2008b; EPA and RMIT University 2009)

Emissions and offset costs		
Energy required	2,594	MWh/year
Offset Cost	12.50	\$/tonne CO_{2e}
Emissions natural gas	57.30	kg CO2-e/GJ
	0.21	kg CO2-e/kWh
	206.12	kg CO2-e/MWh
	0.21	tonne CO2-e/MWh
Emissions boiler	668.34	tonne CO2-e
Total emissions	**668.34**	**tonnes/year**
Annual offset cost boiler	8,354	$
Annual offset Cost	**8,354**	**$/year**

Table 32: Solar collectors for hot water heating (ATA 2009; EECA 2009)

Solar hot water		
EcoSolar 5.9 HE 270HS		
Houses	1,000	houses
Offices	300	offices
People	4	people/house
Water tank	270	Litre
Panels per house	5.6	m^2/house
Total area of panels	7,280	m^2
Cost EcoSolar 5.9 HE 270HS	1848	$/system and house
Systems needed	1,300	systems
Total cost	**2,402,400**	**$**
Maintenance cost	**Low**	
Regular energy use for hot water heating	4,720	MWh/yr
Energy savings with solar	0.80	
Energy use with solar hot water heating	**944**	**MWh/yr**

Table 33: Approximate costs Scenario 4

Scenario 4		
Wind energy, PV panels, boiler, solar hot water		
Total installation cost wind energy	46,893,815	$
Total installation cost solar energy	14,272,891	$
Total installation cost hot water heating	2,402,400	$
Total installation cost boiler	1,670,073	$
Total installation cost	**65,239,179**	**$**
Annual offsetting cost	**8,354**	**$**
Wind and solar		
Maintenance Cost	Low/Medium	
Boiler		
Annual fuel cost Australia	52,488	$
Annual fuel cost Europe	166,328	$
Annual offset cost	8,354	$
Annual running cost	146,019	$
Solar hot water		
Annual running/maintenance	Low	
Total annual cost Australia	**206,861**	**$**
Area required for solar collectors	**7,280**	**m^2**
Area required for PV	**7,939**	**m^2**
Turbines required	**297**	**turbines**

Additional calculations

The general NPV and that accounting for the carbon price, calculated without inflation was based on:

$$NPV = \sum_{n=1}^{15} \frac{annual\ savings}{(1+i)^n} - initial\ investment$$

$i = interest$

Annual savings differ when the carbon price is included, but the basic formula is the same. In the case of accounting for the inflation, it is estimated that the first savings are calculated on the value of the dollar at the end of that year. The calculations are based on the NPV being:

$$NPV = \sum_{n=1}^{15} \frac{annual\ savings\ (1+in)^{n-1}}{(1+i)^n} - initial\ investment$$

$i = interest \qquad in = inflation$

Table 34: Costs for importing energy to a development (Wilkenfeld 2005; Australian Federal Treasury 2009)

Business as usual		
Annual electricity output	**8000**	**MWh/year**
Annual hot water heating, heating/cooling	**5000**	**MWh/year**
Price electricity	0.17	$/kWh
	170	$/MWh
Price natural gas	12	$/GJ
	0.043	$/kWh
	43.17	$/MWh
Natural gas required	5,000	MWh/year
Electricity required	8,000	MWh/year
Cost electricity	1,360,000	$
Cost natural gas	320,595	$
Average efficiency	0.8	
Total cost	**1,629,784**	**$**
Total cost including predicted carbon cost 2010-2015	**2,246,729**	**$**
Total cost including predicted carbon cost 2015-2020	**2,323,847**	**$**
Total cost including predicted carbon cost 2020-2025	**2,400,965**	**$**
Minimum Attractive Rate of Return (MARR)	8%	
Salvage	0	$

Table 35: Annual savings without accounting for a carbon price

	Investment cost ($)	**Annual cost importing energy ($)**	**Annual cost development ($)**	**Annual saving ($)**
Scenario 1	9,758,231	1,629,784	561,518	1,068,266
Scenario 2	7,580,717	1,629,784	624,938	1,004,846
Scenario 3	9,772,498	1,629,784	563,068	1,066,716
Scenario 4	65,239,179	1,629,784	206,861	1,422,923

Table 36: Cost of producing energy for all scenarios including carbon price (Australian Federal Treasury 2009) (see carbon prices, \$/tonne CO_{2e}, in table 37)

	Time interval	**Carbon released (tonne/year)**	**Cost CO_{2e} ($)**	**Total annual cost ($)**
Scenario 1	2010-2015	4,566	254,414	815,932
	2015-2020	4,566	286,216	847,734
	2020-2025	4,566	318,017	879,536
Scenario 2	2010-2015	4,566	254,414	879,352
	2015-2020	4,566	286,216	911,154
	2020-2025	4,566	318,017	942,956
Scenario 3	2010-2015	0	0	563,068
	2015-2020	0	0	563,068
	2020-2025	0	0	563,068
Scenario 4	2010-2015	668	37,220	244,081
	2015-2020	668	41,873	248,734
	2020-2025	668	46,526	253,387

Table 37: Cost of imported energy, including a carbon price, for 3 different time intervals (Australian Federal Treasury 2009)

Cost importing energy without carbon price	**1,629,784**	**$**
From electricity	340	kg CO_{2-e}/GJ
	1.22	tonne CO_{2-e}/MWh
CO_{2e} from electricity	9,784	tonnes CO_{2-e}
From natural gas	57.30	kg CO_{2-e}/GJ
	0.21	tonne CO_{2-e}/MWh
CO_{2e} from natural gas	1,288	tonnes CO_{2-e}
2010-2015 cost of carbon	**40**	**USD/tonne CO_{2e}**
	55.7	**$/tonne CO_{2e}**
Cost of CO_{2e} for heating etc with natural gas	71,779	$
Cost of CO_{2e} from electricity	545,166	$
Total cost of carbon for imported energy	**616,945**	**$**
Total cost importing energy	**2,246,729**	**$**
2015-2020 cost of carbon	**45**	**USD/tonne CO_{2e}**
	62.7	**$/tonne CO_{2e}**
Cost of carbon for heating etc with natural gas	80,751	$
Cost of CO_{2e} from electricity	613,312	$
Total cost of carbon for imported energy	**694,063**	**$**
Total cost importing energy	**2,323,847**	**$**
2015-2020 cost of carbon	**50**	**USD/tonne CO_{2e}**
	69.6	**$/tonne CO_{2e}**
Cost of CO_{2e} for heating etc with natural gas	89,723	$
Cost of CO2e	681,458	$
Total cost of carbon for imported energy	**771,181**	**$**
Total cost importing energy	**2,400,965**	**$**

Table 38: Annual savings accounting for carbon price

	Time interval	Investment cost ($)	Annual cost importing energy ($)	Annual cost development ($)	Annual saving ($)
Scenario 1	2010-2015	9,758,231	2,246,729	815,932	1,430,797
	2015-2020		2,323,847	847,734	1,476,113
	2020-2025		2,400,965	879,536	1,521,430
Scenario 2	2010-2015	7,580,717	2,246,729	879,352	1,367,377
	2015-2020		2,323,847	911,154	1,412,693
	2020-2025		2,400,965	942,956	1,458,010
Scenario 3	2010-2015	9,772,498	2,246,729	563,068	1,683,661
	2015-2020		2,323,847	563,068	1,760,779
	2020-2025		2,400,965	563,068	1,837,897
Scenario 4	2010-2015	65,239,179	2,246,729	244,081	2,002,648
	2015-2020		2,323,847	248,734	2,075,113
	2020-2025		2,400,965	253,387	2,147,579

Annual cost importing energy- Annual cost development = Annual saving

The exchange rate used from Euro and the American dollars are taken from XE Currency Exchange on 10/3 2009.

Table 39: Approximate currency conversion

1 €	**=**	**$ 1.97**
1 USD	**=**	**$ 1.39298**

The price of natural gas is based on both the average of available European natural gas prices from Energy Information Administration and the Australian price of natural gas. However, since all other assumptions are based on Australian fact, the Australian price is used for all NPV value and total cost calculations. The reason for making a comparison to the European market, is the great difference in price, which may have immense impacts on the decision making process.

Table 40: Costs of natural gas (EIA 2008; Bertsch 2009)

Available European natural gas prices USD/10^7 kCal		
Czech Republic	391.7	
Finland	267.9	
France	414.1	
Hungary	584.2	
Poland	375.1	
Portugal	428.8	
Slovak Republic	420.2	
Spain	380.3	
Switzerland	576.6	
Turkey	440.8	
Total	**4279.7**	
Average	**427.97**	**USD/10^7 kCal**
	10.78	USD/10^6 Btu
	$1.078*10^{-5}$	USD/Btu
	0.037	USD/kWh
	0.051	**$/kWh**
Australia	4.5	$/GJ
	0.016	**$/kWh**