Study into the Feasibility of Ground-Source Heat Pumps at WEST BELCONNEN

Version 1.0

30th October 2014

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Executive Summary

This report examines the potential for supplying the new housing development in West Belconnen with renewable energy, by determining the viable options in terms of efficiency and feasibility.

Though the main aim is to determine the feasibility for energy sourced from the ground, it compares and contrasts the potential for solar, hydro and wind derived energy sources in the West Belconnen context as well. It has been determined that traditional geothermal power generation or heating is not feasible, as the underlying geology does not support the technology required for geothermal energy production. Thus it is concluded that Ground Source Heat Pump (GSHP) systems will be the most suitable.

There is potential for both closed- and open- loop GSHPs at the West Belconnen site, with closed-loop being preferable. However, the preliminary Triple Bottom Line (TBL) analysis shows that GSHPs will have very little negative impact on the environment, with the only real impacts being on initial cost and affordability of housing. It is also important to acknowledge that there is great potential for solar panels as well, which have a similar TBL analysis to that of GSHP; however they fall behind in the ability to produce energy year round, as well as having larger visual impacts.

Though this paper supports and recommends the use of GSHPs in the area, the following pre-installation considerations are advised to ensure success; calculations of the buildings' heat loss, energy consumption and hot water requirements, a consideration of monovalent or bivalent systems, and thorough geographically mapped data of geology and soils.

At an estimate, each residential system would cost around \$32,000 to \$38,000, to install individually. Bulk installation will bring this figure down to between \$22,000 and \$31,000. Running costs will be dependent on a number of factors, such as the size and insulation of the house. The GSHP units are built in an Australian facility that is confirmed to be capable of producing the number of units required for the West Belconnen development.

In order to operate, GSHPs require a small amount of electricity to run the motor and pumps. It is possible to obtain this electricity from solar panels connected to the system to produce a Hybrid Solar Ground Source Heat Pump (HSGSHP), and this is the ideal system in the context of a 6-star energy rating for the proposed development.

1. Introduction

The proposed West Belconnen housing development will be located across the NSW/ACT border; it will provide an additional 6,500 homes in the ACT, and 5,000 in NSW (ACT Govt. 2014). This project is seen as an integral for development in the ACT providing diverse, sustainable and affordable housing for future generations.

Figure 1: Murrumbidgee River at the West Belconnen site

“Sustainability is at the core of the West Belconnen project” - (ACT Govt. 2014). To achieve sustainability, developers are focusing on rehabilitation of natural corridors and waterways, green infrastructure, and renewable energy (ACT Govt. 2014). Further, it is hoped that the eventual development will have a 6-star energy rating (Adams, T. 2014, pers. comm., 9 October). In order to achieve this, the potential for geothermal heating and cooling is being explored for private residences, businesses and community buildings.

This report will first outline what geothermal energy is and why it cannot be used in West Belconnen, looking at the geology of the area. It will then outline a similar source of heating and cooling - ground source heat pumps (GSHP) - and explain why it could be a viable option for the development. This report will outline the engineering aspects of the technology, and examine its environmental costs and benefits. Finally, this report will present a triple bottom line analysis that takes into account the environmental, social and economic implications of installing GSHP technology in West Belconnen.

2. Geothermal Energy

Geothermal energy extraction is the use of naturally occurring subsurface heat for either power generation or heating. Heat within the Earth comes from two primary sources: radioactive decay of minerals (80%) and heat remaining from the accretion of the Earth (20%). The geothermal gradient is the change in temperature from surface to the core of the Earth, and varies significantly depending on location and underlying geology. Geothermal energy is usually generated by drilling deep holes and pumping fluids down, generating steam that turns turbines. Similar technology and infrastructure is employed for heating.

Traditional geothermal energy is utilised in areas around the world where a high geothermal gradient exists. These are locations where the heat below the surface is much hotter than average. Typically these locations are sites where high levels of magmatism occur, such as hot spots, spreading centres and plate margins (Lund, 2005). Countries where geothermal energy is used as a heat or energy source include New Zealand (active plate margin), Iceland (spreading centre and hotspot), United States (hotspots) and Japan (active plate margin).

Australia is a geologically old and inactive country. Geothermal gradients across Australia are relatively cold, with little or no active magmatism occurring underneath the surface (Lund, 2005). Because of this, traditional geothermal power generation or heating is not feasible. Geothermal energy cannot be used at the West Belconnen site, as the underlying geology does not support this technology.

A technology that is often incorrectly labelled as "Geothermal Energy" is incrementally becoming more common in Australia: ground-source heat pumps (GSHPs). This technology does not utilise geothermal energy, but instead uses the upper layers of the soil profile that are heated by the sun as a heat sink or source. The major geological control on the use of this technology is soil depth (Sanner et. al, 2003). At the West Belconnen site, soil depth is highly variable and needs to be methodically analysed to determine the potential of this technology at each new structure. A initial field survey revealed soil depths vary from less than 30cm on elevated ridges to deeper than 3m in gullies and river channels.

3. GSHP Technology

Reversible heat pumps are an increasingly common technology that improves on the efficiency of traditional heaters. The most common of these is the air-source heat pump (ASHP), accounting for nearly 30% of heating in Australian residences (ABS 2011).

Air conditioners are an example of a reversible heat pump that has two modes of operation – heating and cooling. During heating, a refrigerant travels through an exterior coil, where it absorbs the heat of the air. It is then compressed, thereby adding heat to the fluid, and pumped through to an internal coil. The hot fluid decompresses, releasing its heat to the interior of the building. Usually, a fan disperses the heat through a larger portion of the building. The fluid, having lost its heat and pressurisation, is pumped to the external coil and the process repeats.

In cooling, the process reverses. The indoor coil becomes the heat source, and the fluid is compressed and passed to the external coil, where it decompresses and passes heat to the air.

Ground-source heat pumps (GSHP) are a similar reversible heat pump technology that utilises earth, rather than air, as a heat sink/source. Subsurface temperature (7^{o}C-10^{o}C at 5m) is more stable than ambient air temperature, so is a more efficient heat sink/source (Nulux 2014). For example, maintaining a house at 20^{o}C during a 40^{o}C day requires bridging a 20^{o}C temperature difference with an ASHP. With a GSHP, the ground source will be at approximately 16^{o}C, so the system is closing a gap of only 4^{o}C. Because of this, a well-designed GSHP can reach a Coefficient of Performance (COP) of up to 8, while high-efficiency ASHPs are currently limited to a COP of around 4.

The Coefficient of Performance is the ratio of electrical energy input to heat output in a heat pump system. An ASHP drawing 15kW of electrical energy, with a COP of 4, will output 60kW of heat. In contrast, a GSHP drawing 15kW of electricity will output over 100kW of heat because of its higher COP. The COP is highly sensitive to temperature – the smaller the temperature difference (known as “lift”) the more effective the heat pump becomes. In extremely cold regions heat pumps are not viable, as the lift is too great (regardless of air- or ground-source), and radiant heating becomes the more efficient option.

3.1 Closed-Loop GSHPs

Closed-loop systems generally circulate water through the underground portion of the system. Refrigerants have the potential to be environmentally damaging, so are run only through the controlled heat exchanger portion of the GSHP, housed within a secure, accessible cabinet.

In order to maximise heat transfer, closed-loop systems require lengthy underground piping. The longer the fluid runs underground, the closer to sub-surface temperature it will be, and the more effectively the heat pump will operate. The typical piping configurations are as follows:

- Vertical, utilising as little ground space as possible and exploiting the depth of the soil through one or more vertical loops; or
- Horizontal, through several circular loops in series at a constant depth.

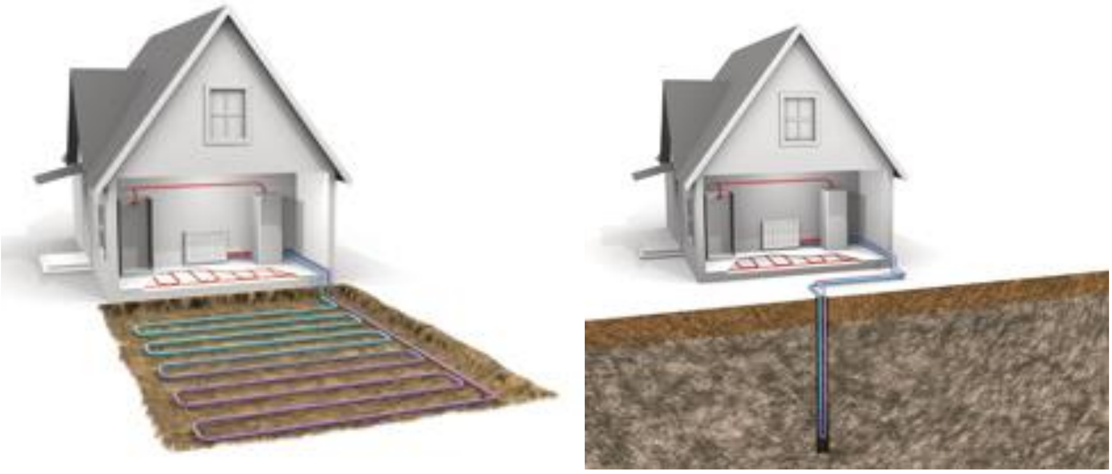

Figure 2: Horizontal (left) and vertical (right) GSHP piping configurations (Thermia, n.d.)

3.2 Open-Loop GSHPs

Open-loop systems draw water from an existing source, circulate it through the heat exchanger, and deposit it back into the source. An open-loop system can be more efficient than a closed-loop system as the drawn water returns to the source, where mixing quickly returns it to its initial temperature. These open systems can raise concern in communities, particularly if drawing from the water table or a communal water source. Refrigerant leaks or pipe contamination may affect the quality of the water source over time, but more research into this is needed.

Figure 3: Open-loop GSHP configuration (EGSHPA 2014)

3.3 Water-source Heat Pumps (WSHP)

WSHPs follow the same thermodynamic theory as GSHPs, using water, not soil, as a heat sink/source. The heat exchangers of these systems are similar to the horizontal closed-loop GSHPs, consisting of a series of horizontal loops submersed in a nearby pond or lake. Water is a better conductor of heat, while maintaining the stable temperatures of soil, so less piping is required. Using existing water sources will also minimise installation costs, as excavation is not required for these systems. Pond suitability will require case-by-case analysis by a specialist, but each of the 36 water quality control ponds could be examined for incorporation into the system.

Figure 4: Lowering a WSHP heat exchanger into a pond (Johnson, M. 2006)

4. Installation of GSHPs

4.1 Local Service Providers

There are currently two primary installation services for ground-source heat pumps in the local area: Direct Energy Geothermal Heating and Cooling, and Touie Smith Sales and Service. The installation of ground source heat pumps is a highly technical and specialised process which requires knowledge and equipment from industry professionals. Further information on the installation process specific to the West Belconnen development thus requires case-specific examination by specialists such as Touie Smith. A formal inspection would be required to enable them to plan a GSHP installation strategy relevant to each household and community building.

4.2 Types of Installation

The ground-side heat exchangers used in GSHPs, as mentioned, are installed in either vertical boreholes or horizontal trenches, depending on the requirements of the site.

For vertical GSHPs, the ground heat exchanger requires digging a number of boreholes. Vertical systems require a large number of holes, and/or hole depths of 20m to 200m, accommodating HDPE pipes with diameters of 100mm to 200mm. Single or double high-density polyethylene (HDPE) U-tubes are installed in the boreholes, and these circulate the heat exchanger fluid (Yang et. al., 2010).

Horizontal GSHPs consist of a series of HDPE horizontal loops or parallel pipes, which require placement in trenches approximately 1m to 2m below ground (Yang et. al., 2010). This configuration is more affected by ambient air temperature fluctuations, and the installation requires a much larger ground area. Once installed, building regulations and standards may prevent development above this underground infrastructure. Methods of placing the heat exchanger under a house's foundation may be feasible in some cases, thereby making effective use of space. In conjunction with slab heating, GSHPs can potentially require little to no additional ground space, and this should be investigate further.

It appears likely that horizontal-loop GSHPs will be implemented in the West Belconnen project. The ability to pre-allocate GSHP infrastructure, rather than retrofitting to existing structures, allows planners to design the loops to have limited impact on future construction. The apparently shallow soil of West Belconnen will also make the vertical construction less effective and significantly more expensive.

4.3 Requirements for Installation in the West Belconnen Development

The process of installing a domestic ground source heat pump typically takes 1-2 days to excavate the area and lay the system (Energy Saving Trust, 2007). The process prior to installation includes a large amount of planning, testing, and evaluation by specialists and contractors. The following pre-installation considerations are advised:

- An accurate calculation of the building's heat loss, energy consumption profile and domestic hot water requirements to ensure the appropriate system is installed.
- A consideration of monovalent or bivalent systems, i.e. heat pumps can cover base heating loads while auxiliary grid systems cover additional peak demand.
- Geographically mapped data, relevant to the installation of GSHPs, will assist in choosing pump locations and the piping configurations for each plot. For example:
    - Soil depth
    - Pressure testing results
    - Ground temperature
    - Rock type
    - Residential structure density
    - Major community buildings (i.e. schools, community centres)

Due to the scale of the project and the multiple systems that may be implemented, a recommendation for the project would be to explore the options and plausibility of setting up a GSHP “mains heating” network to minimise space and costs. A local provider of GSHP technology, Touie Smith, confirms the possibility of this technology, referring to successful cases in Europe. For example, the city of Aurhus in Denmark uses waste heat from a power station and pumps it through water pipes to the town where each house has a meter and a storage tank. Smith suggests that in the case of a large development such as West Belconnen:

“A flow and return ring main can be run and each property has a meter that measures the amount of hot water the premises is drawing. The hot water can be pumped through any distribution system, be it a ducted unit or panels or in slab heating”. (Smith, T. 2014, pers. comm. 28 October).

During operation, the GSHP network will need electricity and water inputs. GSHP power can be developed around the mains electricity network, but the volume of water used by GSHPs will likely be sourced from the town supply, or recycled stormwater.

Each building will require an internal heat exchanger and distributor to take advantage of the GSHP infrastructure. Consultation with specialists will determine the exact specifications of the exchanger and distributor on a per-building basis.

5. Logistical Considerations

The majority of the costs of the West Belconnen project are likely to be absorbed through property sales. Implementing GSHP systems will incur significant additional costs, which will also need to be compensated for. The simplest way to do this is through increasing property prices, but this raises the question of ownership for the GSHP systems.

The most obvious ownership arrangement is that the owner of the property owns the GSHP. The first owner of a home will buy the GSHP as well, paying the full (or subsidised) installation cost. The homeowner would then be responsible for maintenance and repairs of the system (unless under warranty), and would incorporate the GSHP into the cost of the home, should they put it up for sale. The GSHP therefore becomes an investment for the homeowner. As shown in Section 7.1, the payback period of a GSHP is approximately 29 years in the ACT, or 19 years in NSW. However, the average Australian homeowner retains a home for only ten years (Lawless, T. 2013), so this is not a worthwhile investment in their view, especially if maintenance and repairs add significantly to the cost.

Another option would be for an authority (private or council) to retain ownership of the system, while leasing it to the homeowner. The authority would be responsible for maintenance and repairs, but would be able to reduce maintenance costs by servicing the suburb en masse. Setting a low lease rate will extend the payback period of the system, but make the property more attractive to buyers. Homeowners would not be burdened with the non-beneficial investment above, and the authority could continue to charge for the system's use beyond the payback period as a source of revenue.

6. Environmental Considerations

6.1 Benefits of GSHP

The following information is collected from the Ground Source Heat Pump Association (*Ground Source Heat Pump Association, 2011),* unless otherwise indicated.

As mentioned, in order to obtain the desired 6-star energy rating the exploration of GSHP is one of the more plausible options. There are a variety of benefits of GSHPs in general, and in the context of the Belconnen housing project.

6.1.1 Pollution

Due to the fact that GSHP is derived from a renewable energy source, the environmental benefits it offers are a vast improvement on the conventional fossil fuel sourced energy that supplies most of Australia (though some electrical energy is reuquired for pumps, etc). Reducing the amount of pollution due to energy production will have many environmental and social benefits such as:

- Reduced health impacts due to smog
- Reduced emissions of greenhouse gases that cause climate change
- Reduced likelihood of damage to humans and the environment from acid rain
- Reduced land degradation due to clearing for mines and power plants.

6.1.2 Clean Energy

GSHPs have zero onsite gas or carbon emissions, and as a result are very environmentally friendly. It is possible to power the pumping and compression system using renewable energy (such as solar) to further reduce the dependency on fossil fuels, and reach a truly carbon neutral state. Though there are many different factors comprising a six-star energy rating, eliminating carbon emissions for heating and cooling would be a large step towards achieving this, particularly in Canberra where heating and cooling are significant consumers of energy due to a greater variability in climate than coastal regions.

6.1.3 Visual Impact

A GSHP is comprised of three basic elements, as previously described. The largest component (the ground heat exchange loop) is hidden underground. The remaining two components (the pump and the heat distribution system), though above ground, can be hidden in existing infrastructure. The pump is roughly the size of a fridge for an average home, so can be built into the walls of a garage, for example. As a result the visual impact of GHSPs is negligible, especially compared other potential energy sources, such as solar and wind.

6.1.4 Noise

Due to the fact that there are no fans involved in the pumping system (as opposed to an ASHP), GSHPs produce minimal noise.

6.1.5 Efficiency

Though electricity is required to run the pump and heat distributor components of the system, it is used extremely efficiently. As mentioned, the COP of a GSHP can reach nearly 8, so for every unit of electricity into the system, 5-8 units of heat are removed or added to the building.

6.1.6 Servicing and Maintenance

Depending on the components of the system, the life of a GSHP can be between 20-50 years without replacement; however it is still advised that annual inspections be carried out by specialists – ideally those who installed the system. GSHPs require even less maintenance than solar panels, which require cleaning a few times a year to ensure efficiency (*The Solar Company, 2014),* and vastly less than the maintenance of wind turbines, for which installation and maintenance are both particularly costly.

6.2 Environmental Risks Associated with GSHPs

There is very little risk associated with both the installation and running of a closed-loop GSHP system. However, one of the risks to take into account is the potential for the release of anti-freeze from the heat exchanger loop into the environment, with the severity of this risk depending on the anti-freeze used (see table 1). The anti-freeze is required to stop the water in the pipes freezing in colder climates, and is usually mixed at a ratio of 20:80 anti-freeze:water (*Mehnert, 2004).*

Table 1: Cost and Risk Factors for Heat Pump Antifreeze (Heinonen et.al., 1996)

Factor	Antifreeze					
	Methanol	Ethanol	Propylene Glycol	Potassium Acetate	CMA	Urea
Life Cycle Cost	3	3	2	2	2	3
Corrosion Risk	2	2	3[a]	2	2	1
Leakage Risk	3	2	2[a]	1[b]	1	1
Health Risk	1	2	3	3	3	3
Fire Risk	1[c]	1[c]	3	3	3	3
Environmental Risk	2	2	3	2	2	3
Risk of Future Use	1	2	3	2	2	2

Notes:
Ratings– 1 means potential problems and caution required, 2 means minor potential for problems, 3 means little or no potential problems

6.3 Potential for Alternative Renewables:

There is known potential for other types of renewable energy to be used in the Canberra region, with the main options for exploration existing as solar and wind. The Capital Wind Farm near Bungendore demonstrates that the region has the capacity to make use of wind power. However, Canberra's annual wind speed of 8-17km/h (*Bureau of Meteorology, 2014*) does not meet the minimum threshold for an efficient wind farm. Therefore, wind power alone cannot be relied upon to produce enough energy for individual houses, or groups of houses. In addition, the installation and running of wind turbines is a very controversial topic, not only due to the expense of these systems but also because of the 'eye-sore' of the infrastructure, as well as controversial health claims.

The other, debatably more favourable option is that of solar energy, as has been installed in southern Canberra. This was the solar farm in the country be connected to the national grid. There is also potential for small scale solar systems which could power individuals' houses, or indeed a larger scale farm in the case of the West Belconnen community. This farm could, for example, be installed on the discarded landfill site, as this is not suitable for housing. The potential for solar is explored in more detail below, and there is indeed the option that it could co-exist with the GSHP system to produce completely non-dependent renewable energy in the form of Hybrid Solar Ground Source Heat Pump Systems (HSGSHPS).

Figure 5: Royalla solar farm (ABC 2014)

7. Cost of GSHPs at the West Belconnen Site

The high cost of installation for GSHPs is one of the major barriers to its wider application, and the breakeven between installation cost and energy savings is one of the most important factors in deciding to implement GSHP systems. The West Belconnen development is no different, and the financial cost of implementing GSHPs is particularly important for such a large installation. GSHPs differ in size and complexity and will require exact specifications to be costed accurately.

The ground heat exchanger, and its installation, is the most expensive of the system's three main components, accounting for up to half of the total system cost (Florides and Kalogirou, 2007). Drilling costs are dependent on the drilling depth and ground composition, with both of these varying on a home-by-home basis. In general, the drilling cost of GSHPs is more than \$30 per metre (HeatSpring Magazine 2012), and boreholes may need to be drilled to a depth of 200m+ (ADP Group Ltd, 2014), depending on the configuration, which means vertical drilling may cost over \$6000 per house. Prices from local specialists of GSHP installation claim that once drilling and grouting of pipes is completed, costs can be as great as \$10,000/house, and thus is avoided where trenching is possible. For horizontal trenches, local specialist T. Smith suggests that six trenches, 30m long x 1.8m below the surface is usually adequate, resulting in around 180m of trenching all up, costing around \$4000. This includes installation of high-density Polyethylene (HDPE) or polybutylene (HDPB) piping, chosen for their durability and chemical stability.

At an estimate, a single house system will cost around $32,000 to $38,000, and running costs will depend on a number of elements, such as the size and insulation of the house. However, due to the fact that all systems are made in Australia, and that the factory is capable of mass-producing units for a project of this scale, it is estimated that a price reduction of 20%-30% on fully installed systems may be achieved. (Smith, T. 2014, pers. comm. 28th October)

7.1 Payback Period

Assuming a saving of 30% is made on an initial estimate of $32,000 per house, a GSHP will cost approximately $22,400 to install on a new West Belconnen home. A slab-heating system will save around 70% of the energy used by an ASHP, or an estimated $800/annum in the ACT ($1300/annum in NSW). (Smith, T. 2014, pers. comm. 28 October). As shown in Figure 6, this equates to a payback period of 28 years for homes in the ACT, or 18 for NSW, at current electricity prices.

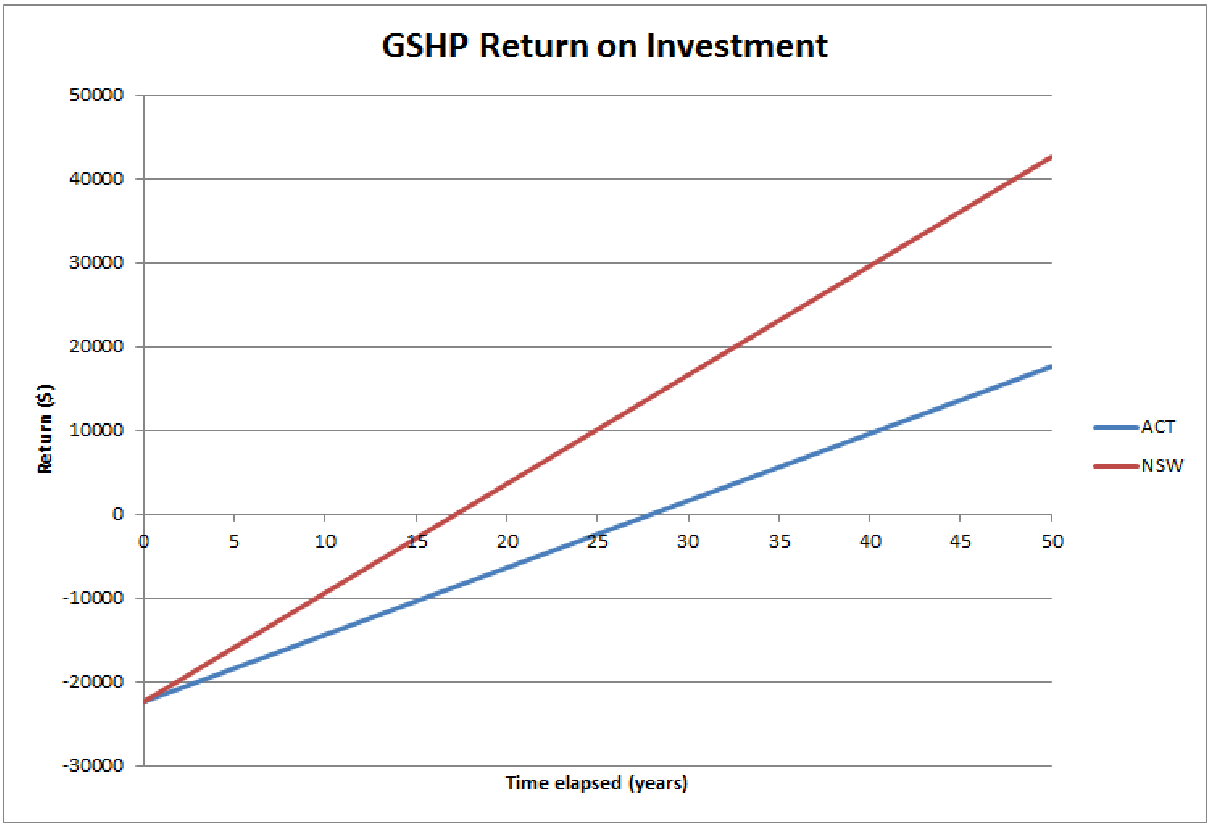

Figure 6: Return on GSHP Investment

This estimate is subject to many factors. Any additional installation or running costs will extend the payback period, but electricity price increases will result in a quicker rate of return.

7. 2 Cost of Alternative Renewables

It is worth exploring the cost of installing and maintaining the other primary options for renewable energy:

- Photovoltaic cells (solar power)
- Wind turbines
- Hydroelectric

7.2.1 Photovoltaic Cells

Solar power is one of the more likely renewable energies to be implemented, along with GSHP, because Canberra is high in solar exposure, with mean daily sunshine of 7.6 hours/day. In summer, mean daily sunshine is around 9 hours/day, dropping to around 5-6 hours/day in winter (*Bureau of Meteorology, 2014)*. It is relatively easy to install on a small scale operations system, or can be implemented on a larger scale, such as the Capital Solar Farm.

- **Efficiency**: Most domestic scale solar panels convert about 15-22% solar radiation into electricity (*PvPower, 2012).*
- **Cost**: Current rebate of approximately $800 per kW installed, with total prices dependent on the size of the solar system needed. An average four person household consumes about 25 kilowatt-hours per day, so would require a 6.5 kW system to cover 100% of the household's electricity consumption (*AGL Energy, 2014).* In Canberra, a 5kW system costs about $8,600, with a reimbursement of 7.5c for every kWh that a household "exports" to the electricity grid (*SolarChoice, 2013).* In addition, federal solar rebates exist on systems up to 100kW in the form of Small-Scale Technology Certificates (STC's) which are in effect an up-front rebate on the cost of installing a solar PV system, (*SolarChoice, 2013).*
- **Maintenance:** There is some minor maintenance required for solar panels. They do require cleaning a few times a year in order to ensure they maintain their efficiency. Additionally, it is important that surrounding vegetation is managed to prevent shade limiting the panels' exposure, and there are costs associated with such maintenance.

Panels need to be checked every three months, and every 12 months junction boxes, fuse boxes, breakers, inverters and mounting systems need to be re-inspected.

7.2.2 Wind Turbines

Wind Turbines are unlikely to work in the area. Even 'Small Wind Turbines' designed as individual units for single houses or buildings would require a higher average wind speed then occurs in the Belconnen region. Having said this, there are small scale individual turbines which exist in the region, such as at the West Belconnen Child and Family Centre. However it was determined (through direct contact) that these only serve as supplements to conventional energy. (*At this stage we are still waiting on quantitative statistics of the efficiency and production of the turbine).*

7.2.3 Hydro-electric

There is potential to harness the flow of the Murrumbidgee River to generate energy through the installation of hydroelectric infrastructure. In general, hydroelectric infrastructure is expensive but the costs would be significantly reduced by removing the need for a dam. Ginninderra Falls (Figure 7) produces a significant height difference in the river's flow, which translates to high potential energy that can be harnessed. Though expensive, it would have greatly reduced effects on the surrounding environment, including wildlife and land use, than traditional hydroelectric dams.

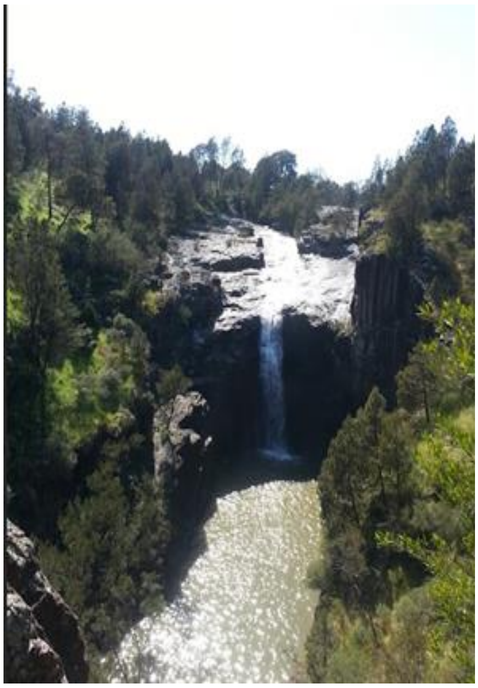

Figure 7: Ginninderra Falls

8. Triple Bottom Line Analyses

The framework for the Triple Bottom Line Analysis (TBL) will have the following structure of a preliminary assessment; each criterion will be identified as having a Positive, Negative or N/A effect.

8.1 GSHPs

Table 2: TBL analysis of GSHPs

Social	Economic	Environmental
Community and individual health	Act government budget	Biodiversity
Access to services	Productivity and innovation	Landscape changes
Affordability of housing (initially)	Income levels and distribution	Heritage
Access to social networks and community activities	Employment	Natural resources
Human rights	Small business impact	Environmental quality
Gender	Skills and education	Greenhouse gas emissions
Indigenous culture and multiculturalism	Investment and economic growth	Water
Impacts on different age groups	Consumption	Air
Disability	Competition	Microclimate
Disadvantaged and vulnerable	Cost of living (initially)	Visual quality
Justice and crime	Procurement	Waste

8.2 Analysis of GSHP Positive and Negatives

Table 3: Analysis of GSHP Positives and Negatives

Criterion	Outlined negative	Outlined positive
Housing and affordability of housing (initially)	Price of alternative renewable energy increases initial cost of house	
Community and individual health		Promotion of ecosystem services
Employment		Potential local employment for infrastructure installation
Productivity and innovation		Promoting green technology
Investment and economic growth		Large capital potential in sustainability
Cost of living (initially)	Initial larger investment in property for occupant – required to stay in house for a number of years to see return.	
Landscape changes	Though minor, there will be some above ground infrastructure (which can be hidden in building space). However there are potential issues with the heat transfer loop effecting the temperature of the surrounding ground making growth of vegetation difficult	
Natural resources		Decreases dependency on conventional resources
Environmental quality		Positively promotes the environment
Greenhouse gas emissions		Severely reduced or minimised if HSGSHP is developed
Air		Cleaner air on both a large and small scale
Micro climate		Once again positively promotes air quality
Waste		Produces no waste

8.3 Solar Power

Table 4: Solar power TBL analysis

Social	Economic	Environmental
Community and individual health	Act government budget	Biodiversity
Access to services	Productivity and innovation	Landscape changes
Housing and affordable housing	Income levels and distribution	Heritage
Access to social networks and community activities	Employment (installation)	Natural resources
Human rights	Small business impact	Environmental quality
Gender	Skills and education	Greenhouse gas emissions
Indigenous and multicultural	Investment and economic growth	Water
Impacts on different age groups	Consumption	Air
Disability	Competition	Microclimate
Disadvantaged and vulnerable	Cost of living (initially)	Visual quality
Justice and crime	Procurement	Waste

8.4 Analysis of Solar Power Positives and Negatives:

Note that the TBL analysis for Solar is almost identical to that of GSHP, with the one greater negative of 'Visual Impact', and the lack of 24/7 energy production.

Table 5: Analysis of solar power positives and negatives

Criterion	Outlined Positive	Outlined Negative
Housing and affordable housing (initially)	Price of alternative renewable energy increases initial cost of house	
Community and individual health		Promotion of ecosystem services
Employment		Potential local employment for infrastructure installation
Productivity and Innovation		Promoting green technology
Investment and Economic Growth		Large capital potential in sustainability
Cost of living (Initially)	Initial larger investment in property for occupant – required to stay in house for a number of years to see return.	
Landscape changes	Large amount of above ground infrastructure vastly changing landscape	
Natural resources		Decreases dependency on conventional resources
Environmental quality		Positively promotes the environment
Greenhouse gas emissions		severely reduced or indeed completely minimised if HSGSHP is developed
Air		Once again positively promotes air quality
Micro Climate		Cleaner air on both a large and small scale
Visual Quality	Depending on size of system used, there is a fairly large visual impact.	
Waste		Produces no waste

Both TBL analyses produced show a very similar overall impact, with the main difference being the lesser visual impact associated with the GSHP, due to the nature of infrastructure being mainly underground. It is also important to acknowledge that GSHPs are less dependent on the weather; the thermal mass of the soil retains heat regardless of cloud cover or temperature, and overnight. Though solar panels can still produce electricity in clouded conditions the overall efficiency is greatly reduced, and production ceases entirely at night.

Final Recommendations and Conclusion

It is determined that of the viable types of alternative heating, GSHP systems, though initially expensive, will be one of the most feasible options. Additionally, it is recommended that the aforementioned HSGSHP system be investigated further, especially if the development is to have a 6-star, carbon-neutral energy rating, as these systems produce absolutely no emissions whatsoever.

A detailed analysis of soil depth should be undertaken across areas of the development where GSHPs are most likely to be installed. The most appropriate starting point for such an analysis would be at the "community centre" location, as GSHP technology is to be installed there first. It is also possible to develop a theoretical model of soil depth across the landscape taking into account topography, parent material, climate, biological, chemical and physical processes in using a Geographic Information System (GIS) (Nicotina et al., 2011).

Market research will need to be undertaken into the effects of the initial high capital cost of GSHP technology on homebuyers. This research should incorporate an investigation into which financial scheme; leasing or owning, is the most attractive. It should also take into account that the West Belconnen housing development is aimed at first home buyers to some extent, and increasing the cost of a house could significantly impact on this demographic. Additionally, as the West Belconnen development straddles the border of NSW and ACT, there are financial implications for the integration of this technology into households; mainly that there could be dramatic differences in electricity pricing. This complex issue would need to be further researched prior to any construction taking place.

Although this system would reduce the total amount of energy needed to heat and cool a house, it still requires some electrical input. To make this process completely carbon neutral and work towards gaining the 6 star energy rating, alternative energy sources should be seriously considered as inputs into the ACT mains grid. Further, the impact GSHP may have on water sources such as the water table, ponds or lakes, needs to be investigated to ensure the long term use of refrigerants does not impact on the environment or people.

This environmentally friendly technology is relatively unknown in Australia, so there is room for government or business level promotion strategies. With the right marketing, GSHPs may become a highly desirable feature in future homes or commercial buildings. GSHP projects of this scale have not been completed in Australia, meaning the ACT will be able to further its image as a pioneer in sustainability and social development, on both a national and international scale.

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List of Abbreviations

ACT	Australian Capital Territory
ASHP	Air-Source Heat Pump
GSHP	Ground-Source Heat Pump
HSGSHPS	Hybrid Solar Ground-Source Heat Pump System
NSW	New South Wales
TBL	Triple Bottom Line