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Valuing Geothermal Projects Using an Enhanced Levelised Cost Framework

Walter Gerardi, Stephen Hinchliffe

Jacobs SKM, Level 11, 452 Flinders Street, Melbourne 3000 Australia

Walter.Gerardi@Jacobs.com

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ABSTRACT

Investors and policy makers have, in general, adopted a levelised cost approach to demonstrating the relative attractiveness of alternative generation options. Levelised costs are used by project developers and investors/funders in determining which projects to develop or invest in. They are often used by policy makers in comparing the relative merits of different power generation technologies, particularly renewable energy technologies. However, in this respect, the use of levelised cost as a comparator undervalues the benefits of geothermal energy projects as it does not recognize the important benefit that geothermal energy projects have over most other renewable technologies, such as providing base load power and protection against possible future fuel price increases or carbon cost imposts. As such, geothermal energy is often undervalued by policy makers and investors leading to the potential for ill informed decision making and inappropriate investment decisions.

This paper describes and proposes an alternative to use of levelised costs to value geothermal project options compared to other, intermittent, renewable energy and other fossil fuel technologies, using the GENCHOICE framework. This framework captures the benefits of geothermal energy as being base load, a major contributor to carbon emissions reduction and an efficient user of the electricity grid. The framework measures levelised cost at a common point of comparison, in this case the regional reference nodes. The levelised cost is estimated as a function of capacity utilisation and explicitly includes system costs as a function of intermittency, in addition to breaking down capital and operating costs into major components. The framework also uses a probabilistic approach to provide a value for the hedge against future fuel and carbon price rises.

The approach has been used to determine the advantages of geothermal relative to other fossil fuel and renewable technologies and suggests that the cost difference is much narrower when all these other factors are taken into account. Further, the risks associated with geothermal technologies are also less compared to many other generation technologies. Once these additional factors are taken into account, the differential narrow between the cost of geothermal generation and the cost of other forms of renewable and fossil fuel generation.

The approach has implications for both investors and policy makers. Investors need to be cognisant of the relative advantages of alternative generation technologies and the added benefits that differing technologies including geothermal can bring to their portfolio. Policy makers need to be aware that basing policies on simplified levelised cost calculations may lock in the use of technologies that do not minimise electricity generation costs in the long term.

The approach also provides guidance on which aspect of the technology would benefit from further research and development. It is clear that further works on firming up the geothermal resource base and to improve the efficiency of the energy conversion process would go a long way to reducing costs of geothermal and lock in its comparative advantage to other renewable technologies.

1. INTRODUCTION

There are a number of ways to value power projects. The most common method is the levelised cost approach, which involves the calculation of an average cost of generation for a power project over its life, where cost includes a return to capital invested as well as fuel and operating costs. The levelised cost has several uses: as a benchmark of the price that is required to justify investment in the power project, to enable comparison with alternative generation options to determine optimal investment options and as a comparator of the relative merits of alternative technologies. The latter is typically used by governments to determine support for alternative technologies (Hinchliffe et al 2010).

The levelised cost is at best only a guide to relative cost competitiveness and typically undervalues the benefits of alternative technologies particularly renewable technologies. In this paper, the limits of the levelised cost approach are explored in terms of evaluating the benefits of geothermal technologies. The approach developed in this paper extends the levelised cost framework to provide a nuanced evaluation of the comparative cost that explicitly considers the comparative advantages of the geothermal technologies relative to other renewable energy and fossil fuel technologies, explicitly considers the premium value of the technology as a hedge against a number of uncertainties affecting future electricity markets and its option value in managing future uncertainties. We demonstrate that the levelised cost approach may not capture the full costs of intermittent renewable generation arising from it possibly being an inefficient user of transmission grid infrastructure and arising from the need to invest in peaking plant and or energy storage schemes to compensate for this intermittency. Also that the result of this intermittency is that base load coal fired generation is driven by the market to be a load follower, reducing the efficiency of the plant, and increasing CO_2 emissions that negate some of the benefit of certain intermitted renewable technologies.

2. WHY IS IT NECESSARY TO GO BEYOND LEVELISED COSTS?

Levelised cost analysis has traditionally been used to provide an indicator of the long run marginal cost of alternative electricity generation technologies. Whilst this approach was satisfactory the screen technology options for future development in a centrally controlled for planning investments in generation, the move towards market based dispatch of electricity generation has limited its usefulness.

Recent trends that have lessened the applicability of the levelised cost approach (as has been traditionally formulated) include:

- Market based mechanisms have led to an increasing focus on differing needs for generation services. Participants now explicitly and differentially value additional services provided by generators such providing reliable power for base load customers, providing load following services, providing other ancillary services and so on. This makes using levelised cost on a presumed capacity factor less useful for appraising technologies that fulfil different functions in electricity.
- Generators now face a range of risks based around uncertainties in future demand growth patterns and costs of key inputs. These risks may lead to trends such as increased investment in low cost simple cycle gas turbines or smaller plant that better matches projected load growth and reduces capital risks. A simple levelised cost approach does not explicitly take account of the risks faced by investors.
- Technology and policy developments are becoming increasingly unpredictable, with the potential for game changing developments occurring during the operating life of a new plant that could undermine the returns of the plant. Basing investments or support polices on current comparisons of technology costs risk the locking in of less than technological pathways that are not robust or flexible to future developments.

These trends means a more sophisticated approach is required to compare the comparative costs of alternative generation technologies.

3. COMPARING COST COMPETITIVENESS

In this section we compare cost competitiveness of renewable and fossil fuel technologies. We outline a range of approaches to measure cost competitiveness using costs in Australia as a point of comparison. The analysis is illustrative only but it will enable a comparison of the relative merits of different valuation techniques.

3.1 Standard Approach: levelised cost approach

Levelised cost of energy (LCOE) is a proxy for the long-run marginal cost of generation from a technology. The metric allows comparison of technologies with different time streams of capital, fixed and variable operating costs and translates this cost into a common metric. Mathematically, the levelised cost is given by:

$$LCOEi = \sum\{(Cit + OCit)/(1+rt)\}/\sum\{(Git)/(1+rt)\} \qquad (1)$$

where $LCOE_i$, C_{it}, OC_{it}, G_{it}, r are the levelised cost of generation in *$/MWh* for a technology *i*, the capital cost stream for technology *i* in year *t*, the operating cost (fuel, ancillary plus O&M costs) for technology *i* in year *t*, the generation level of the technology *i* in year *t*, and the discount rate usually set at the weighted cost of capital for a merchant plant, respectively.

The period of analysis is usually the technical life of a particular plant.

More sophisticated calculations of levelised costs use discounted cash flow modelling (real, post tax), where the levelised cost is the price of energy exported needed to set net present value to zero for a given discount rate.

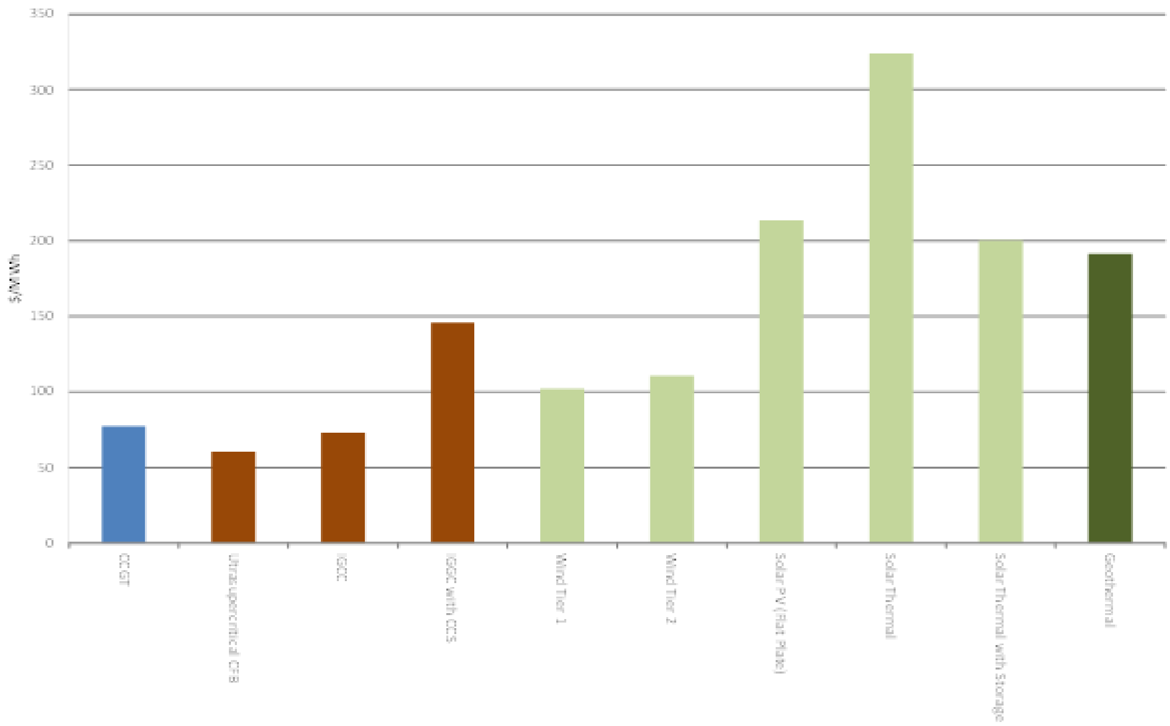
The LCOE can be used for a number of purposes. First, as formulated above, it can be used to determine the average price a generation technology would need to receive for it to be economic (including providing a sufficient return to capital). Second it can be used to determine cost competitiveness across technologies. Investors can use it to compare relative costs of a power project relative to other technologies or projects. Policy makers also use it to compare the costs across a range of technologies to gauge the impact of technology support policies.

An example of its application is shown in the following chart, which illustrates the LCOE for generation technologies in Australia' National Electricity Market projected for 2015. Conventional coal plant remains the lowest cost generation option mainly due to the high gas prices assumed. Wind generation remain the lowest cost source of renewable energy generation due to historically low turbine costs and reasonable wind regimes. The analysis also indicates the high cost of less mature renewable energy technologies such solar thermal and geothermal.

The advantages of this approach to providing comparative costs is that it is simple to calculate and easy to understand the findings. The analysis can be more sophisticate by indicating a range of costs based on reasonable variations in key assumptions such as capital costs and fuel prices.

But there are some inherent disadvantages to this approach that lead to an overestimate of costs of generation of geothermal and can underestimate the benefits of geothermal and other renewable energy technologies.

First, the analysis treats costs for each technology as homogenous. In fact, costs for each technology can vary depending on location of the plant (which can affect transmission connection costs, marginal losses during transmission to load centres and delivered fuel costs), the availability and incidence of the resource (which can affect the level of generation possible from variable sources of renewable energy such as wind and solar), and size of plant. To take an example, we now examine the cost curve for proposed wind farms in the national electricity market, as shown in Figure 1. The LCOE estimates range from around $90/MWh to $190/MWh. Clearly, geothermal even at current costs would be competitive against the higher cost wind projects.



Source: Jacobs analysis. Assumes weighted average cost of capital of 10% in real terms, project start in 2015, mean capacity factors (e.g. 33% for wind and 92% for coal and gas plant).

Figure 1: Generation mix to meet Australia's emission targets.

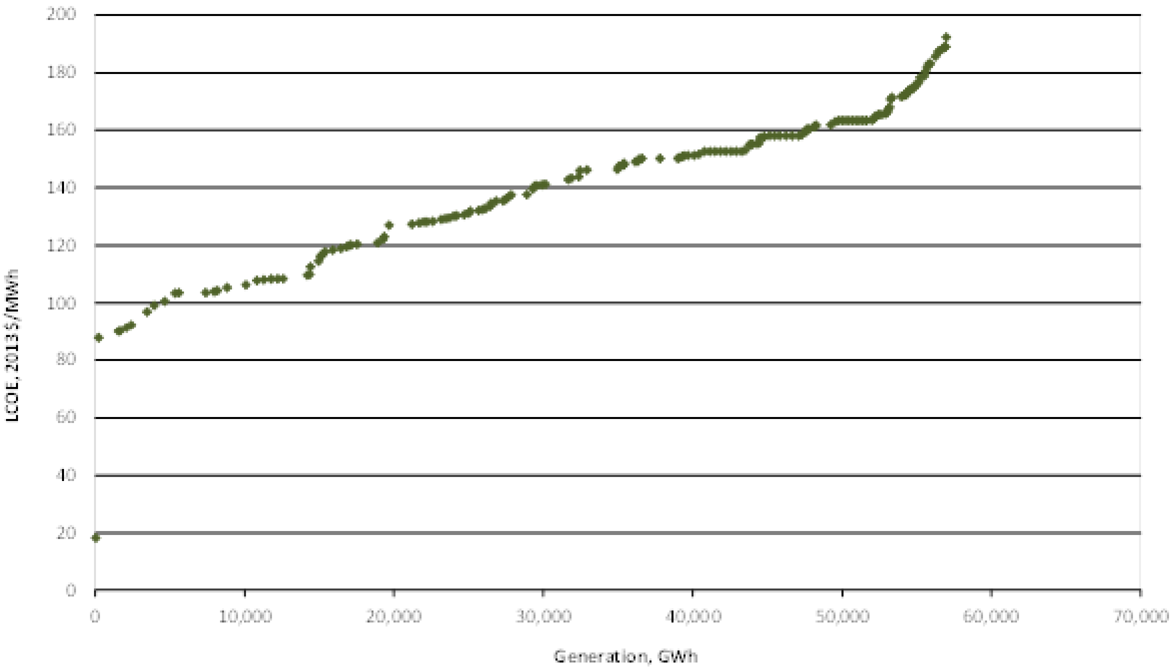


Figure 2: LCOE cost curve for wind generation in the National Electricity Market

Second, the LCOE technique is silent on the stage of development of a technology. The costs estimates for the geothermal technology suitable for deployment in Australia in Figure 1 reflect costs for a 'first-of-a-kind" or early deployment costs1. Capital

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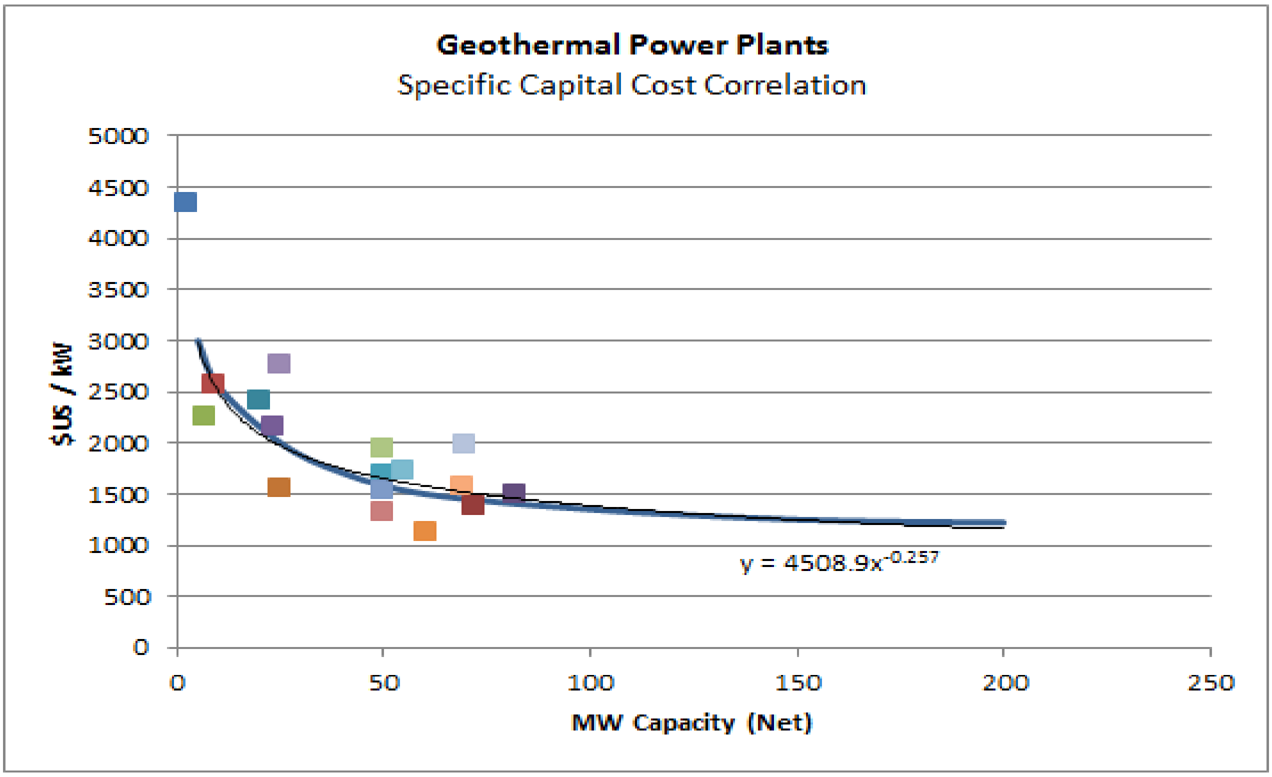
[1] Geothermal technology based on enhanced geothermal systems or hot sedimentary aquifer based geothermal are relatively novel options for the Australian market

costs for the early tend to be high as assemblage of the plant is untried, non-standard parts are being used, lack of experience in constructing parts of the plant (e.g. establishment of the wells), poor economies of scale in the manufacture of plant parts and there is a tendency to over engineer the plant. As plant builds accumulate the learning by doing tends to reduce the capital costs of construction of the plant. The cost decrease through learning by doing can be a rapid process – witness the price decrease in cost for solar PV systems – and this is possible for geothermal technology as standard equipment is being used as a whole and the main novelty of the technology is around the development of geothermal wells.

Similarly, experience with technologies can lead to increasing size of plant. The increasing size of plant over time will impact on cost in $/kW$_e$ terms through economies of scale.

An example of the change in cost on a $/kW$_e$ basis for geothermal energy by size of plant is shown below:



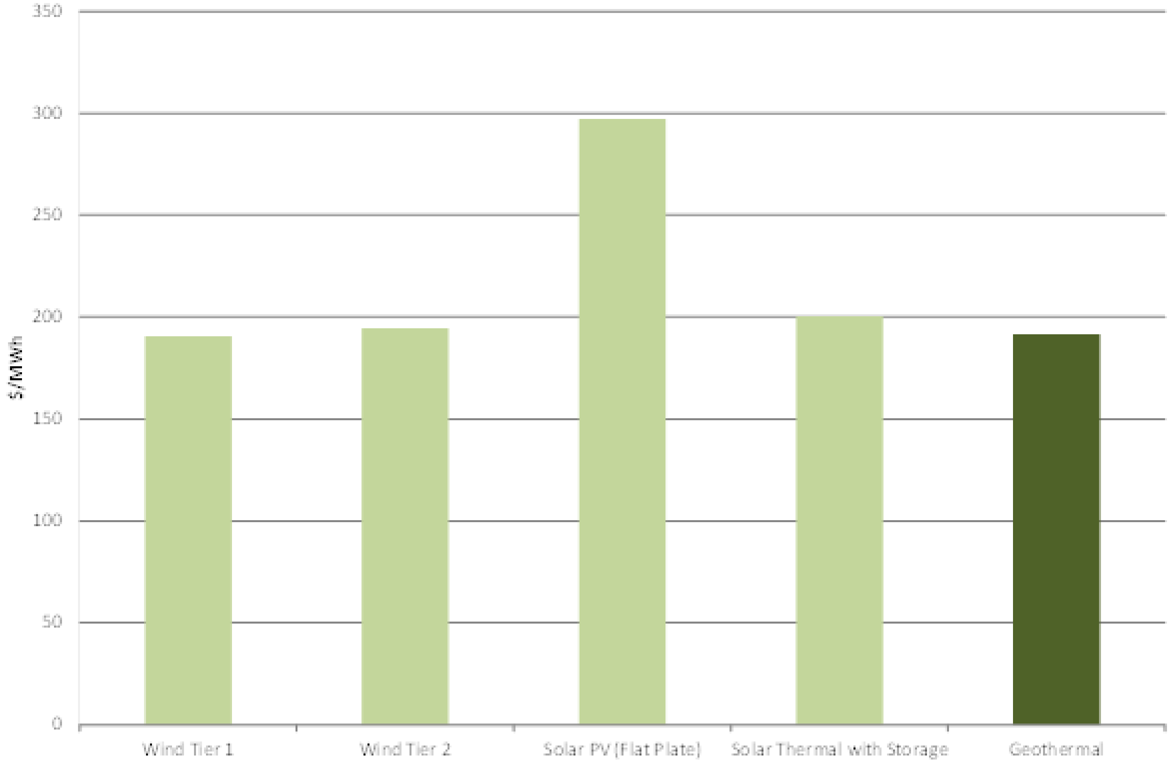
Source: Jacobs SKM Data from Geothermal Project Jacobs SKM has supported.

Figure 3: Example of impact of size on economies of scale and $/kW installed costs

Third, the analysis does not consider the relative operating advantages of base load power plant and the levelised cost of intermittent resources does not capture the expenditure required elsewhere in terms of strengthening grid infrastructure to cope with intermittent power flows from generators and in the building of peaking plant capacity or energy storage capacity to compensate for the intermittency of non-base load renewable energy systems. The electricity market is not a homogenous market selling electrons. The market also has a time dimension (base-load, mid-merit and peak markets) and quality dimension (reliability of supply and firmness of capacity available). Geothermal technologies can reliably supply power on a base load basis, one of the few renewable technologies that can do so reliably. To consider the implications for base load duty, consider the levelised cost of energy when electricity has to be sourced from a thermal generation source or renewable storage option to back up renewable energy supply to ensure high capacity factor (see Figure 5). The LCOEs of the technologies become similar as a result.

The LCOE approach does not take into account the inherent risks faced by fossil fuel technologies. Renewable technologies such as geothermal have no or low carbon emissions and so are not exposed to the impact of carbon pricing or carbon mitigation policies. Renewable technologies are also not exposed to price rises in fuel prices, which is an acute risk for natural gas-fired generation. Avoiding these risks adds value to renewable energy projects (Awerbuch, 2003).

Considering the possible variations in fuel prices, carbon prices and capital costs, the LCOE can be reformulated to obtain expected costs. The following chart compares the simple LCOE (shown in Figure 1) with the LCOE where the values for key assumptions are weighted by the probability of the distribution of their possible values. The chart illustrates that consideration of possible variation in the values of key inputs generally increases the expected costs for fossil fuel technologies and reduces the gap between fossil fuel and renewable energy costs – for example making wind generation at least as competitive as fossil fuel generation. Put another way, the impact of potential adverse variations on key costs increases the premium (above fossil fuel generation costs) that investors are willing to accept on the cost of renewable energy generation.



Source: SKM analysis. The costs comprises the LCOE of the renewable generation cost plus the cost of obtaining power from a backup fossil fuel plant or storage medium

Figure 4: LCOE for base-load duty

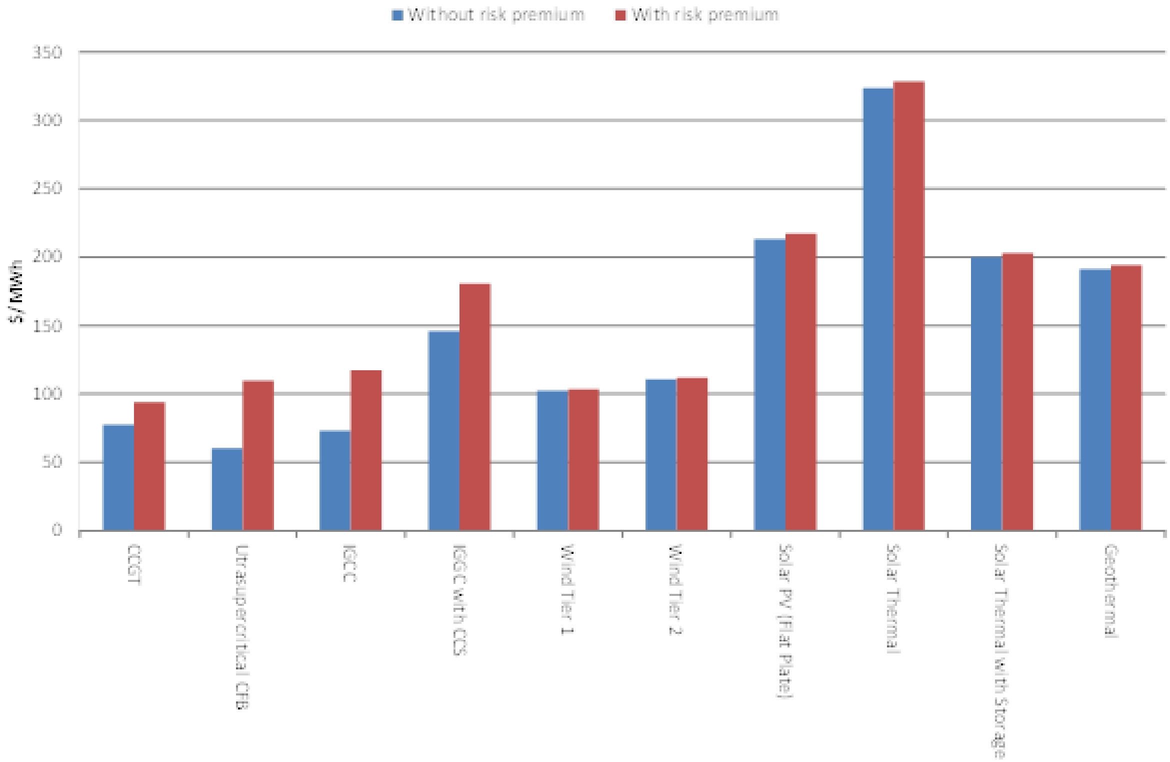


Figure 5: LCOEs with and without premiums for potential variations in key costs

Other factors that make the LCOE approach problematic include:

- Does not take into account for the significant development risks that are included in the capital costs and returns to capital expected for technologies like geothermal during the early phases of development of these technologies;
- Does not adequately account for projects with long lead times (such as typical geothermal projects) ;

- Does not take into account the high return on equity required for high risk projects.
- Does not take into account the trade-offs involved in increasing unit size (economies of scale versus increased market and resource risk). Although cost of fossil fuel options are often favoured by the economies of scale that come with increased unit size, the LCOE method does not take into account the increased market risks incurred with entry of large sized units.
- Does not take into account revenue risk (Gross, et. al., 2007)
- Does not take into account the cost of externalities such as:
  - The inefficient use of grid infrastructure
  - The need to build peaking plant or energy storage plant
  - The reduced efficiency of coal fired plant being forced to be load followers rather than base load

The levelised cost methodology can be enhanced to consider externality costs where information is available. For example, recent studies by the NREL have indicated system costs of intermittent generation being around $2/MWh to $5/MWh. Recent studies by AEMO have also determined similar costs at current levels of deployment. However, these cost estimates are averages across the grid and there may be localised variations in costs which would increase the cost of intermittent generation substantially more in some regions. These regional variations in costs are typically ignored in levelised cost analysis, especially for policy making purposes.

3.2 Risk based approaches

Standard approach relies of specifying set values for uncertain assumptions. Sometimes sensitivity analysis is deployed to get a potential range of values. A probabilistic approach to uncertainty around input values goes one step further by specifying each assumption as a distribution of possible values so that a distribution of possible LCOEs for each technology can be derived. If done correctly, this probabilistic analysis provides additional information to investors and policy makers in terms of the spread of potential costs and the relative riskiness of different generation technologies.

The basis of this approach is to specify probability distributions for all uncertain assumption variables. GENCHOICE can specify probability distributions for the following variables: carbon mitigation policies (start of those policies and the cost or subsidy impact of those policies), capital costs, fuel costs, transmission connection costs, marginal network loss factors, labour costs and externality taxes. In terms of geothermal plant, resource potential and availability can also be represented as a distribution curve.

A typical representation of the distribution of values for an input is shown in Figure 6. This is shown for the input of geothermal resource potential. The shape of the distribution and the parameters describing the shape can be derived either from a statistical analysis of historical data, an understanding of the underlying factors driving input values or from subjective judgments of specialists.

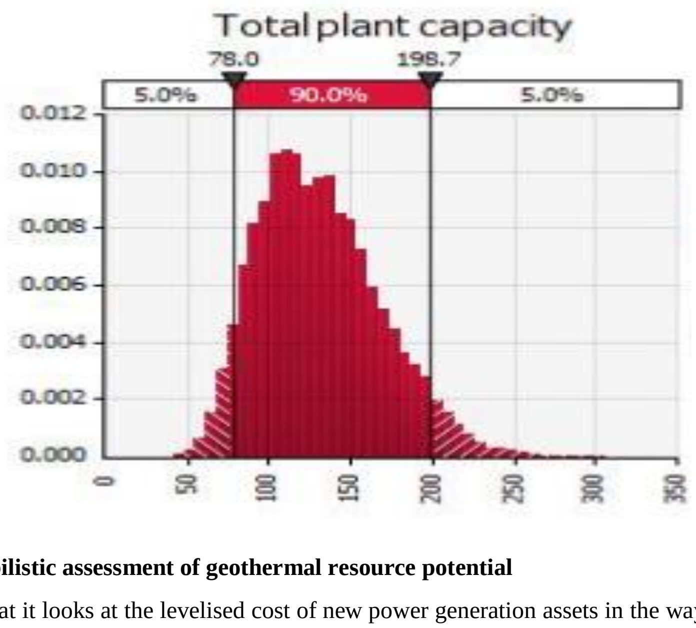


Figure 6: Example of probabilistic assessment of geothermal resource potential

The value of this analysis is that it looks at the levelised cost of new power generation assets in the way that sophisticated investors would. Investors in power assets have consider multiple potential outcomes for the future value of key inputs. For example, gas prices can exhibit marked volatility – witness the recent sharp rise in gas prices in the eastern seaboard of Australia. The potential variations can affect both the cost of relative generation options and the financial viability of those options. Investors may (depending on their appetite for risk) wish to choose or pay a premium for options that, although have an initially higher cost than other options, have lower exposure to adverse movements in key input costs. For example, an investor may wish to pay a premium for renewable energy options that do not have any exposure to fuel price risk and carbon mitigation risk.

This approach also provides additional information for investors and policy makers. The output specifies a range of possible levelised costs for each technology, with technologies with more certain input values or less potential volatility in input prices having a narrower distribution of levelised cost values. The spread of the distribution gives investors additional information on the inherent riskiness of a technology. As illustrated in the following diagram, a generation technology may have a higher cost than another, but there is a high probability that the alternative technology may end up having higher costs. In the diagram, technology

B has a higher average LCOE vale than technology A. But there is a wider spread of possible LCOE of technology (due to plausible variations in key input variables) that mean that there is a not insignificant probability of technology A having a higher LCOE than technology B (the shaded area represent the probability of technology having a higher cost than the average cost of technology B)

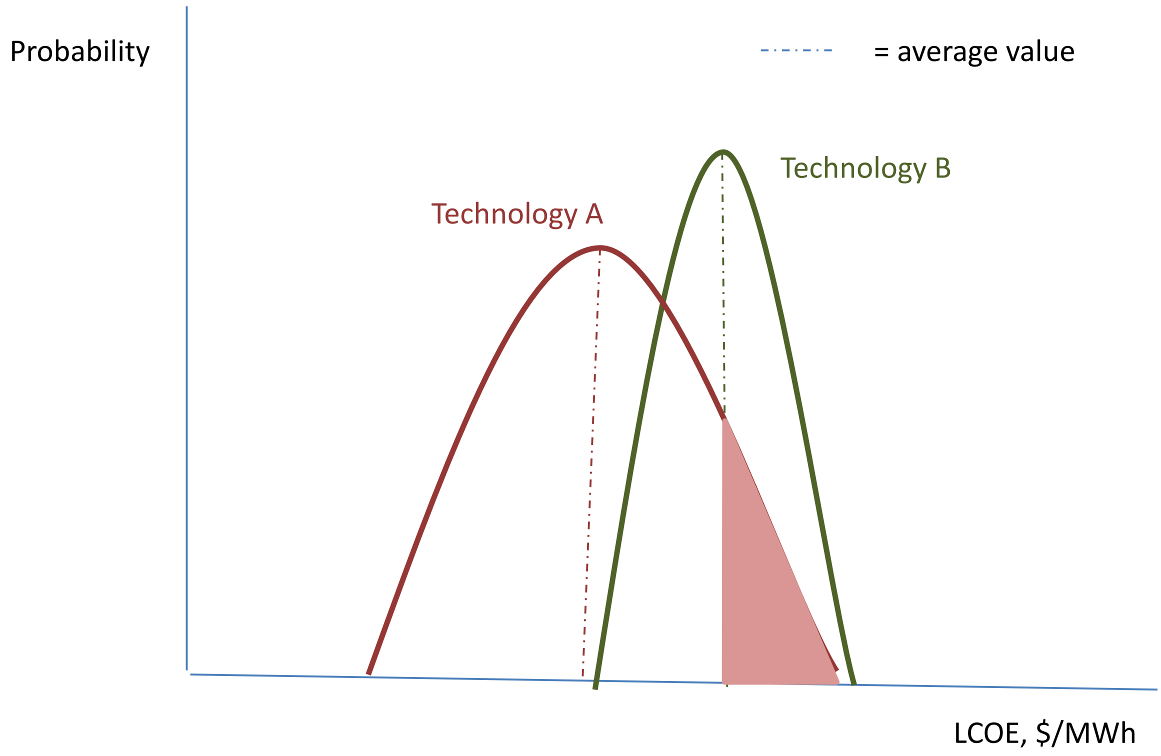


Figure 7: Illustration of distribution of LCOE for two technologies

The implication is that given the range of possible future values for key inputs, an investor may be willing to invest in a technology even do it has a higher cost on mean assumptions if there is a reasonable probability of even higher costs for some of the other technologies.

The approach can be extended to consider key financial risks facing geothermal technologies. The biggest risk, or barrier, to this technology is the high cost to prove the resource before FID and hence before debt financing becomes available. Funding of the high cost exploration and production drilling to achieve sufficient capacity under the well head to de-risk the project to the point where a commercial bank will provide debt funding is typically done from shareholder funds (equity). The probabilistic approach can place distribution of potential values for equity premium and the length of time it takes to prove the extent of the resource[2].

The approach can be extended to consider some of the other costs that could potentially be incurred by the intermittent renewable energy technologies. For example, ancillary service costs (in $/MWh) could rise exponentially with increased penetration of wind or solar PV generation. The uncertainty in the range of future ancillary costs can be explicitly modelled. The same applies to other network costs associated with higher penetration of intermittent generation.

The main advantage of this approach is that explicitly considers the uncertainties in key input variables, which means cost comparisons based on LCOE can be extended to consider the plausible distribution of costs for each technology. This technique can be used to place premiums for technologies avoiding input uncertainties and can also provide insights into some of the key technical/commercial risks inherent in each technology. The method is particularly when comparing the cost of renewable technologies with fossil fuel technologies as many renewable energy technologies typically do not face uncertainties in fuel prices and externality penalties that hamper fossil fuel technologies.

The main disadvantage of this method is that it is data and information demanding. The availability of rich historical data sets can help overcome this limitation. The veracity of the method depends on their being enough data or information to correctly specify the distribution of potential input values.

3.3 Option valuation

This approach takes the risk approach one-step further by valuing the ability of investors to alter, delay or defer investment until better information is known – say for example on the future of carbon mitigation policies. Is useful when:

[2] It can be used to determine the reduction in costs and equity premiums if the initial resource proving activity is aided by the government funding or general data collection.

- Investments involve large upfront capital costs
- The investment is irreversible

In other words, electricity generation especially renewable electricity generation!

It is the concept of option valuation that will led investors to invest in OCGT (instead of a CCGT) as an investor can design the OCGT to be able to be converted into a CCGT if market conditions become favourable in the future.

The ability to provide this optionality provides inherent advantages to a technology but the option value is not easily estimated by the LCOE methodology.

The option value can be significant for renewable energy technologies including for geothermal generation. Renewable technologies can be more modular or have smaller unit sizes so can be more easily be built to match increments in load growth as they happen. Securing a geothermal resource and proving it has an option value because then the resource is ready to be exploited when the market is favourable. Carrying out research and development of renewable technologies has a similar option value.

4. POTENTIAL COMPARATIVE ADVANTAGE OF GEOTHERMAL TECHNOLOGIES

We have developed a more sophisticated version of the levelised cost approach that accounts for the issues discussed above and applies a probabilistic framework that explicitly accounts for the risks facing different generation technologies. We illustrate the approach by undertaking a comparative analysis of alternative technologies and determining the potential comparative advantage of the geothermal technology. The comparison is done for the Australian electricity market.

4.1 Characteristics of geothermal generation

Conventional, magmatic geothermal energy has a track record of over one hundred years of successful development. Currently some 10,000 MWe of electricity is generated world-wide. This generating capacity is growing at three percent per annum. It is conservatively predicted that 1000 MWe of new generation will be installed worldwide within the next five years using current technologies. The leading countries in terms of installed capacity are the USA, the Philippines, Italy, Indonesia, Mexico, Iceland Japan and New Zealand.

Large scale use of geothermal resources for electricity generation has traditionally been restricted to countries where high temperature resources occur close to the surface, usually related to magmatic activity. Technological developments, including the development of commercial scale power plants that can operate at lower temperatures, and permeability stimulation of wells through use of fracture techniques and well section isolation3, have now reached the point where such restrictions on depth, temperature and the natural occurrence of a heat transportation fluid may no longer be so critical. This has resulted in the development of lower temperature geothermal resources such as Hot Sedimentary Aquifer (HSA) geothermal resources and Hot Rock (or engineered geothermal resources). These three geothermal resources are represented in Figure 8 and are each described in brief below.

Magmatic geothermal projects rely on magmatic heat coupled into an underground reservoir. This magmatic heat is typically developed by dormant or recently (in geological terms) extinct volcanos or other regions where the earth's crust is relatively thin and magma can rise to become proximate with an underground water reservoir. As such, opportunities for development of magmatic geothermal projects are predominantly in regions proximate to or on tectonic plate boundaries, such as the 'ring of fire' in around the Pacific Plate. As well as being generally hotter than HSA or EGS resources, they are typically shallower (with wells being typically sub 1.5km) and hence benefit from lower drilling costs than HAS and EGS. Given their higher enthalpy, than EGS or HSA resources, they are more suited to steam Rankine cycle power plant developments enabling large scale developments using relatively inexpensive power main power island components utilising single flash or double flash technology (where the bi-phase brine and steam from the geothermal well is flashed and the steam fed directly into a steam turbine). The lower temperature EGS, and particularly HSA resources, as a generality, lend themselves more to slightly lower scale and more expensive binary (either steam or organic Rankine cycle) power plants (where the hot brine is supplied to a heat exchanger rather than directly to the turbine).

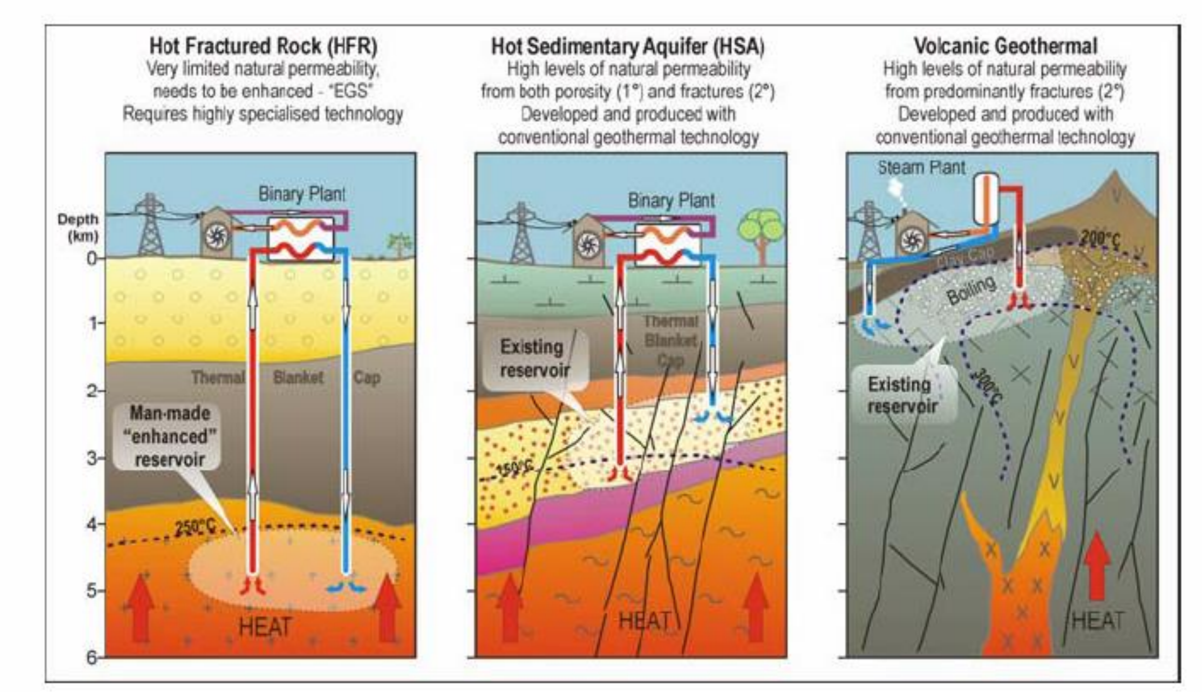
HR projects are focussed upon certain rocks, mainly granites, with elevated radiogenic components that have produced heat through decay of naturally occurring isotopes - primarily uranium, thorium and potassium. Thermal insulation in the form of low thermal conductivity sediments overlaying the granite body is a critical feature. Depths within the 3 to 5 km range are typically considered as the exploration target to achieve desired temperatures of between 200 to 280°C. The rocks require fracture stimulation to provide pathways for thermal fluids to migrate from injection to production well to extract heat. There are a limited number of EGS plants operating around the world which are relatively

HSA resources tend to be cooler than the HR systems, but contain large volumes of hot water. In HSA systems, conductive energy over time has heated up sedimentary aquifers. In Australia, there is an existing HSA power plant at Birdsville (QLD), and several 100MW of HSA power plants operating in the US, with a few small commercial installations in Europe. HSA resources are naturally permeable and don't require to be 'engineered' through rock fracturing (stimulation), as such HSA developments are seen by some as being less technically challenging that HR developments.

Of the three resource types above, magmatic geothermal resources are least abundant but least risky and least expensive to develop. HSA resources are more abundant but of lower temperature and more expensive to develop than magmatic resources whilst EGS

[3] For further information, see Geothermal Industry Technology Roadmap, a companion document to this Geothermal Industry Development Framework, available at: www.geothermalframework.net.au

resources are arguably the most abundant but the most risky (currently) and most expensive to develop of the three. It is this greater abundance of HSA and EGS resources and wider geographic spread over magmatic resources that attract the attention of developers, renewable energy advocates and politicians alike.



Decreasing risk and cost

Courtesy: Hot Rock Limited

Figure 8: The three primary types of geothermal systems

The benefits of all three types of geothermal system based power plants over other established renewable technologies are:

- Base load power generation hence an efficient user of the grid infrastructure;
- High availability and capacity factors;
- May be controlled and dispatched by grid operators in the same way as fossil fuel plant

For large resources, projects are typically developed in stages, with additional power plant being added as the resource is demonstrated and the power generating potential becomes proven.

4.2 Geothermal project costs

A breakdown of the costs of the different types of geothermal projects, based on a 30 MW_e scheme, with medium enthalpies, (temperatures and flow rates), average well depths and average overall build difficulty for each geothermal resource type is provided below in Table 1.

Table 1: Typical geothermal project costs

Cost item	Unit	Magmatic Geothermal Source	Hot Sedimentary Aquifer Geothermal Source	Engineered Geothermal System Geothermal Source
Wells	$/kW$_e$	1,250	4,545	7,500
Steam Above Ground System (SAGS)	$/kW$_e$	400	550	550
Power plant	$/kW$_e$	1900	2700	2400
Overall Cost	$/kW$_e$	3,550	7,795	10,450

Cost item	Unit	Magmatic Geothermal Source	Hot Sedimentary Aquifer Geothermal Source	Engineered Geothermal System Geothermal Source
Combined availability/plant capacity factor	%	93	93	93
Availability/capacity factor adjusted cost	$\$/kW_e$	3,817	8,382	11,237
Operation and maintenance (fixed) power plant (major event) (once every 3 years)	$/event	1,250,000	1,000,000	1,250,000
Operation and maintenance (fixed) power plant (Minor event) (twice every three years)	$/event	300,000	250,000	300,000
Operation and maintenance (variable) power plant	$/kWh	0.01	0.01	0.01
Operation and maintenance (variable) steam field	$/kWh	0.006	0.006	0.007

Source: Jacobs SKM survey of Australian geothermal developer costs for the Australian Geothermal Energy Association and SKM cost data from projects Jacobs SKM has supported (Hinchliffe et al 2010).

Whilst the headline $/kW cost is high compared to say, $\$3,000/kW_e$ for wind, when capacity factor and availability is taken into account, magmatic geothermal systems compare very favourably for capacity/availability factor adjusted cost for wind of $\$8,571/kW_e$ (assuming a combined capacity/availability factor for wind of 35%) and HSA schemes become comparable with the cost of wind powered generation.

4.3 Approach to assessing comparative advantage

The analysis is undertaken using Jacobs SKM's GENCHOICE model, an analytical frame work that is used to assess least cost options for new generation. The model allows appraisal of the full cost of each option over time (and proposed start date) and for the identified need (base load, mid merit, peak) as identified by determining costs for specified capacity factors. The model can be used to screen the technologies that are likely to be the competitive options for new generation and to assess the comparative advantage of each technology.

GENCHOICE is an Excel based model using @Risk software to shape key input (and therefore output) distributions. The object of the model is to calculate the long run marginal costs (LRMC) of the generation in each region of the wholesale market. The basis of the model is to incorporate the key uncertainties facing investors in new fossil and renewable energy generation.

The model comprises a framework for calculating the LRMC at a common reference price (typically a major load centre) to represent the cost to deliver electricity to major customers for each option.

The model is structured as follows:

- Each major and connected load region is modelled.
- Within each region, the cost structure of the major technology options for new generation is modelled. The cost structure builds up the cost from its key components such as capital costs (and the key components of capital costs), fuel costs (including delivery costs) and operating costs. For each technology, the long run marginal cost for generation is calculated, using the levelised cost formula above. The long run marginal cost is a function of the level of utilisation (or in other words, the segment of the market being catered for: base load, intermediate and peak duty) and the year in which the plant is commissioned.
- Costs are transferred into a regional reference node price by applying a marginal loss factor. The marginal loss factor is dependent on the location of the plant relative to the load centres. Both shallow and deep connection costs are also modelled.
- Key inputs are modelled as distribution of potential vales as shown in Table 2.

The distributions cover a range of future uncertainties facing investors in new generation. First, there are macroeconomic uncertainties (interest rates, exchange rates, world GDP and labour costs), which indirectly affect capital and operating costs and the investment hurdle rate (weighted average cost of capital). Second, there are regulatory or policy uncertainties, particularly in relation to carbon abatement policies and market rules. Third, there are uncertainties related to international commodity prices, which affect capital costs and fuel costs. Finally, there are uncertainties over future trends in technology costs, particularly for novel technologies.

Table 2: Inputs modelled as distributions

Input	Type of distribution	Key parameters
Nominal interest rate	Normal with lower and upper bounds	Mean, standard deviation, minimum and maximum values
US$:A$ exchange rate	Logistic	Mean and beta values
Average weekly earnings (real terms)	Triangle	Minimum, most likely and maximum values
Global carbon target	Discrete	Four targets modelled (including no game), each with a different subjective probability of starting
Carbon pricing start date	Discrete	Probability of each global target being in existence in each year
Carbon price	Normal distribution with upper and lower bounds for each carbon target	Mean, standard deviation, minimum and maximum values
Debt to equity ratio	Triangle	Minimum, most likely and maximum values
Base project life[4]	Triangle	Minimum, most likely and maximum values
Technology cost trends	Represented by a power curve over time, where the power factor is a normal distribution with minimum and maximum deviations	For the power factor parameter, mean, standard deviation, minimum and maximum values (expressed as a proportion of the mean value).
Initial cost decrease	Triangle distribution with parameter values dependent on estimates of the cost change	Minimum, most likely and maximum values
Metal price index	Extreme Value distribution	α (location) and β (shape) values
Brown coal prices	Normal distribution reflecting LRMC of mining with upper and lower bounds	Mean, standard deviation, minimum and maximum values
Black coal prices – cyclical variations	Log logistic distribution	Γ, α and β values
Black coal prices – long term trends	Discrete distribution	Probabilities for three scenarios over future coal price
Natural gas prices – long term trend	Discrete distribution	Probabilities for five scenarios over future coal price

Source: Jacobs SKM analysis

Capital costs are a key cost component. Capital costs are constructed from a number of components. First, for each technology, there is the international turnkey cost in US$/kW. This cost varies over time based on the long term cost trends (reflecting learning by doing and economies of scale in production), cyclical movements in metal prices and construction costs. This cost is then converted into an Australian price through a US$:A$ exchange rate and a premium for construction in Australia (reflecting lower productivity levels in construction in Australia). Capital costs also include the cost of well-development in the case of geothermal technologies.

Interest during construction is also calculated (using the interest rate of debt) to arrive at an overnight cost.

Operating costs are broken down into fixed and variable cost components. Variable costs include water costs, ash disposal costs, chemical costs and internal energy usage. Fixed costs cover the cost of labour and maintenance costs.

Transmission costs cover the cost of connection. A deep connection cost (that is costs related to the upgrade of the wider shared transmission network) is only applied in the event that regulations change to accrue these costs on new generation (this choice is itself a discrete distribution). For embedded generation options (such as cogeneration), transmission costs may be avoided. A benefit (in the form of a negative cost) is allowed if the regulations allow for such benefits.

5 COST STRUCTURE OF GENERATION TECHNOLOGIES

Different technologies have different compositions of upfront, fixed and variable operating costs. Figure 9 illustrates the cost breakdown for a range of fossil fuel and renewable energy technologies.

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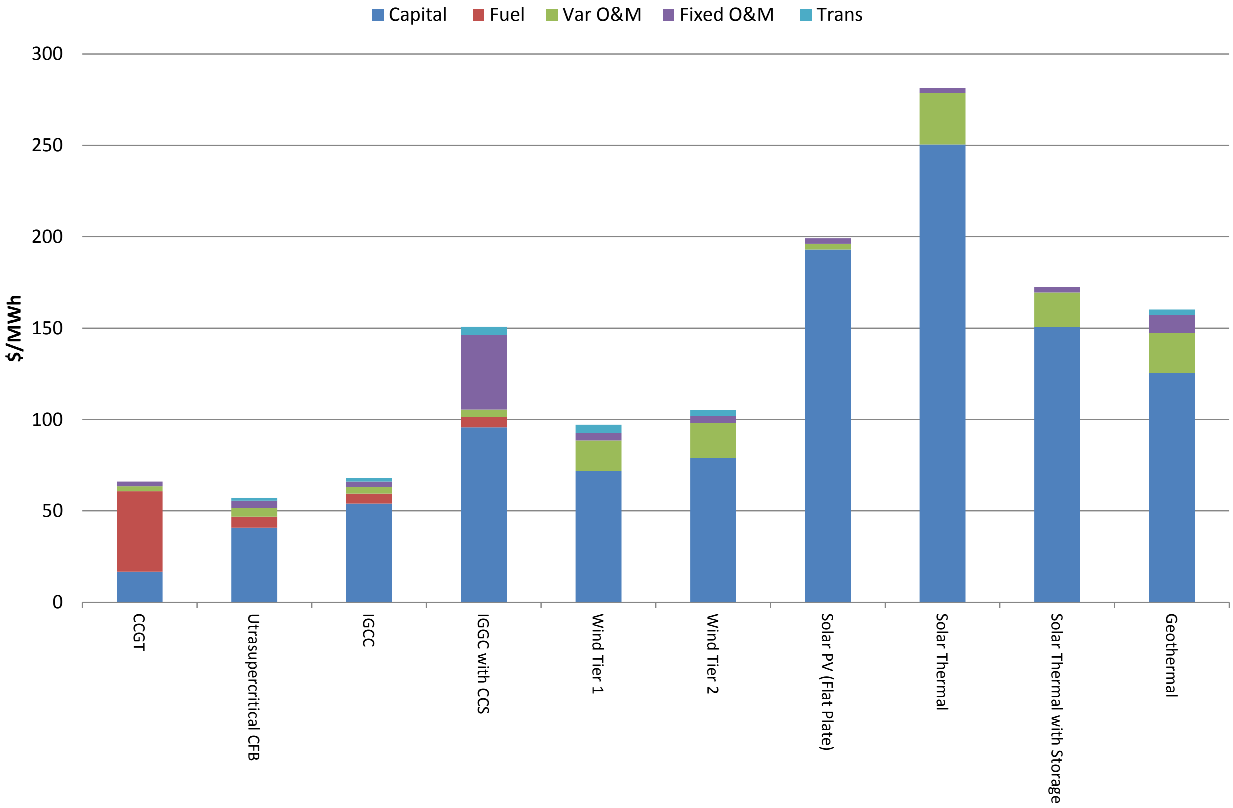
4 Represents the technical life of a Combined Cycle Gas Turbine technology. Project lives for other technologies are related to this being either shorter or longer based on analysis of historical life for each operating technologies and estimates of economic life for novel technologies.



Source: Jacobs SKM analysis using GENCHOICE model

Figure 9: Cost breakdown of generation technologies, Victoria

Like other renewable energy technologies, a significant portion of the cost of geothermal generation is upfront capital cost including the cost of proving the resource and developing the required wells. Ongoing operating costs (including the cost of transmission losses) are minimal as long as the geothermal plant is located near the load.

The upfront cost of geothermal in Australia is relatively high compared to say wind and natural gas because of the following factors:

- Relatively new technology in the Australian context with costs for for first or early plant.
- High resource development cost component. Around 35% to 40% of the upfront capital cost is spent on proving the geothermal resource and developing the wells. The cost is made even higher by the high return to equity required for resource development because of the high risk involved. Well costs also increase exponentially with depth (SKM 2007). Further, there may ongoing capital cost incurred to construct replacement wells.
- Potentially widespread buy sporadic distribution of the resource

However, a simple comparison of the levelised cost masks some important factor that could mean that geothermal could become relatively competitive with other option.

First, as already mentioned, geothermal in Australia is relatively disadvantage by its early stage of development compared with the more mature alternatives such as wind and even solar PV. First of a kind plant tend to be more expensive than follow up plant as more experience is gained in developing wells, understanding the energy potential of the resource and constructing plant (especially ancillary plant). The above analysis assumed a first of a kind cost of around $8,500/kW to $9,000/kW. Potential reductions on this cost are feasible with experience and with improved economies of scale with development of larger resources. If you take the example of large scale solar thermal with storage, which is at a similar stage of development as geothermal in Australia, we have already witnessed around a 20% reduction in capital cost from the first 50 MW_e plant to the second 50 MW_e plant built in Spain.

Second, drilling costs comprise 35% to 40% of total capital cost. There is potentially a significant learning by doing effect: success rate of proving and developing wells improves from early exploratory phase to development and then operating phase.

Third, costs of geothermal projects vary with drill depth, geology, and location. Just as there are favourable wind sites, there will be favourable geothermal resources with an extensive relatively shallow geothermal resource located close to the grid or major loads. Moreover, some sites may be located close to other heat loads meaning an additional market for the steam once it has gone through the steam turbine and before reinjection into the basin.

Fourth, the LCOE analysis, as described previously inexhaustible, does not account for the inherent advantageous of geothermal compared with fossil fuel and other renewable technologies. Local air pollutants and CO_2 can be low. Land requirements are not as extensive as for other options. The above ground of geothermal plant have a generally proven performance although there will be some work to adjust to Australian conditions. There is no –ongoing fuel cost meaning that project is not exposed to volatility or rising fuel price (or any associated externality taxes) during its operating life. And development of a geothermal project can be scaled to match load, achieving economies of scale as development progresses. A more nuanced analysis (using the probabilistic or option methods) would add value to the geothermal projects.

Fifth, and importantly, the technology offers stable and base load energy during its operating life. Stable generation provides an advantage against intermittent sources of generation such as wind and solar. At current levels of deployment of intermittent generation in Australia, the cost of intermittency (ancillary service and associated network costs) is relatively low at around \$2/MWh to \$5/MWh due to the relatively low level of deployment and widespread diversion of the generation. However, the cost is likely to increase exponentially if penetration increases to above around 30% of average demand. Base load generation can provide a significant advantage in that high upfront costs can be spread over more output.

There are some cost disadvantages to the technology. Resource depletion can happen at individual wells necessitating the need to develop replacement wells. Sulphur and even CO_2 content can be high in some reservoirs. Land or right of way issues can hinder optimal development of the resource. There is limited ability to follow load and respond to demand. As previously mentioned there is a high resource development risk and an associated long project development cycle. Fields may require sophisticated maintenance and extensive drilling for larger plant.

5.5 Valuing the comparative advantage

To illustrate the potential value of the technologies advantageous, we use the GENCHOICE model to highlight the potential additional value brought about by some of these advantageous. The analysis considered:

- And a shadow cost for carbon emissions of around \$20/t CO_2e
- Based on recent research on the cost of intermittency, added a cost of \$5/MWh for additional ancillary service cost and around \$5/MWh for network stability costs
- Added a premium of \$5/MWh for natural gas plant and \$2/MWh for coal plant to reflect the potential cost of variable future prices for these fuels

The results of the analysis are shown in Figure 10. Although the cost gap is now narrower the high development costs for geothermal is still a disadvantage compared with mature renewable energy and fossil fuel technologies.

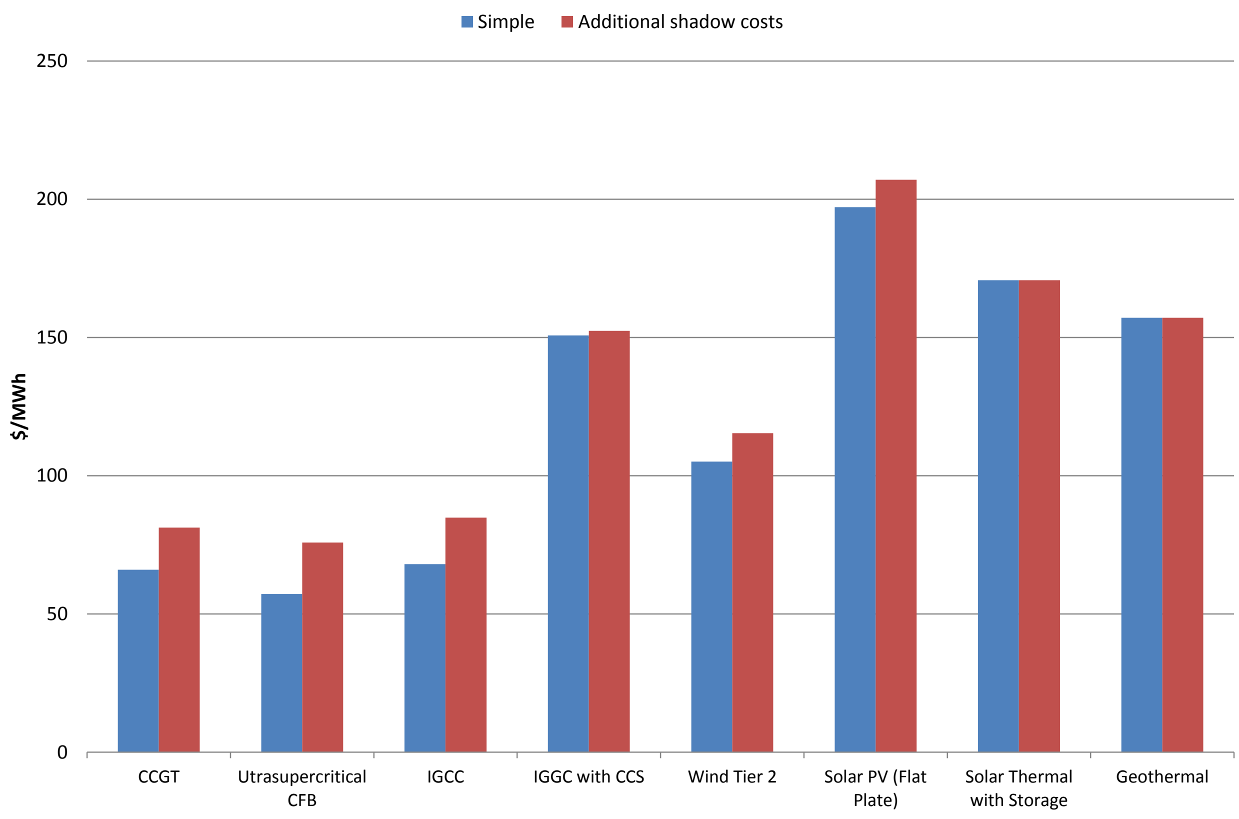


Figure 10: Cost comparison when carbon price and fuel risk plus cost of intermittency are considered.

The main prospect for geothermal technology to reduce cost to become competitive is to reduce its upfront cost. The fact that the technology can achieve base load duty means that capital and development costs do not need to be as low as wind and solar PV generation for the cost to be commensurate. Analysis using the same analytical framework indicates that capital costs need to reduce to around $6,300/kW (a reduction of around 30% on current estimates) to achieve similar costs to wind generation.

Other advantageous include the technology being dispatchable (to time of high prices if necessary and to minimise system ancillary costs), no fuel cost other than the need to drill make up wells every three or four years to maintain production from the resource, and potentially reliable fuel cost in that once the characteristics of the reservoir are known. It is worth noting that few geothermal power plants have been decommissioned in the 100 plus year history of geothermal power development, although some are run below capacity due to resource limitations and the fact that, until recently, injection of brine to preserve reservoir pressure was not standard so this is one further source of cost reduction.

6. IMPROVING THE COST COMPETITIVENESS OF GEOTHERMAL

The above analysis also provides insights into the areas in which research and development should focus on in order to improve the competitiveness of geothermal technology in Australia. It is clear that the focus should be on reducing upfront development and capital costs. This can be done by further understanding of the resource quality of the many identified geothermal fields in Australia and through gaining a better understanding of the associated geology to reduce well development costs and development risks. A number of countries seeking to encourage geothermal development have put in place Government backed geothermal well insurance programs. These programs compensate the developer for the cost of any earlier exploration wells that are not commercially productive, thereby reducing the risk of proving the resource and hence reducing the cost of capital for the early stages of the project. In short, mechanism need to be put in place to reduce the risk and hence cost of capital to the developer for the high capital outlay exploration and resource proving stage of the development.

The Australian Government's recognition of the advantages that geothermal has as base load generation over other renewable technologies would go some way to justifying funding such a scheme.

6. CONCLUSIONS

The electricity sector is likely to undergo a significant transformation over the next few decades in response to wider social and environmental concerns. Simple cost comparisons using LCOE techniques are likely to mislead policy makers and investors into the nature of this transformation. The transformation is likely to involve a mix of technologies, each playing to their comparative strengths. Current policy settings based on levelised cost analysis cannot come to these conclusions.

Investors need to be cognisant of the relative advantages of alternative generation technologies and the added benefits that differing technologies including geothermal can bring to their portfolio. Policy makers need to be aware that basing policies on simplified levelised cost calculations may lock in the use of technologies that do not minimise electricity generation costs in the long term.

Geothermal technologies have an important role to play in this transformation. But simple LCOE analysis would indicate that its costs are higher than alternative technologies. A more nuanced approach taking account of the advantageous of lower operating risk, low pollution profile, base load operation and potential adaptability to market needs is required to recognize the value that geothermal can play in the transformed electricity market.

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