Unitisation of Geothermal Resources: Economics and Policy

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Abstract

Electricity is an essential element of any contemporary society and/or economy. Questions on where, and how efficiently, the available energy is being generated are becoming increasingly important. Secure electricity production is essential for economic growth. Higher fuel costs and recent international initiatives to tackle carbon emissions encourage the use of renewable resources like wind, solar, hydro, and geothermal for electricity generation. This paper focuses on the development of geothermal resources for electricity generation.

Resources can be located on private, community, or public lands. In New Zealand, there are good geothermal resources located on land owned by Maori. Tangible benefits from development may help to fast track gain in economic welfare. However, geothermal development in New Zealand is complicated. Often fragmented land ownership gives multiple access to the same geothermal reservoir while the Crown claims the control of the resource. Robust policies are required to ensure the sustainability of the resources. New Zealand has gone through series of changes to the rules governing the access to the resources from a single tapper policy to multiple access.

This paper reviews access policy to the geothermal resources and the impact of policy on the value and sustainability of the resources. It studies the impact of single, multiple, and co-managed tapper systems on the value of geothermal resources located on Maori land. This research finds that in a fragmented land ownership system with multiple accesses to the resource, lack of available space may lead to faster depletion of the resource and reduction in efficiency of the utilisation.

1. Introduction

Electricity is an essential element of any contemporary society and/or economy. Questions on where, and how efficiently, the available energy is being generated are becoming increasingly important. Secure electricity production is essential for economic growth. Higher fuel cost and recent international movement on tackling carbon emission encourages the use of renewable resources like wind, solar, hydro, and geothermal for electricity generation. Utility of geothermal resources for electricity generation is the main focus of this paper.

Resources can be located on private, community, or public lands. In New Zealand, there are good geothermal resources located on community owned lands, Maori lands. Tangible benefits to local communities may encourage efficient development of the geothermal resource. However, the case of geothermal development in New Zealand can be complicated. Fragmented land ownership gives multiple access to the same geothermal reservoir while the Crown claims control of the resources. Local communities need to know the real value of the resource located beneath their lands in order to be able to estimate the total economic benefits. Government rules and regulations have an impact on a bundle of rights that, in turn, impacts the value of these resources. Property right arrangements have significant impacts on the production possibilities and the growth of an economy (North & Thomas, 1973). Indeed, defining the property rights enables owners to realise the full economic value of their resources. Libecap (1989) believes that property rights provide the basis incentive system that can help to shape resource allocation and the efficient utilisation of scarce resources.

“Under New Zealand law, the owner of land has no automatic right of ownership to any underlying geothermal resource. Land owners above a geothermal system can control surface access to the system.” (WRC, 1992, p. 12) Therefore, the access to the resource is mostly under landowner’s control. In many cases, multiple parties, mostly Maori tribes, own the land above a geothermal reservoir. Traditional Maori society is not against development of the resources for economic purposes as long as cultural values are respected. However, tradition will require developers to protect the resource for present and future generations. It also requires the control and use of the resource to remain with the *kaitiaki* (guardian). Regulations on how and when to develop the resource can have significant impact on the life of the reservoir and profitability. Appropriate assignment of rights internalises externalities and may lead to sustainable business models (Kaffine & Costello, 2011). New Zealand has gone through a series of changes on access policy aimed at optimising use of the resource while minimising the externalities. The introduction of the Resource Management Act 1991 and the 2006 Environment Court decision are the two significant variations to geothermal access policy. Environment Waikato recommended a single operator, single tapper, while the Environment Court decision, in 2006, allowed multiple access to a geothermal reservoir under certain condition (*Decision No. A047/2006* 2006). This paper reviews the likely outcomes of multiple accesses to the geothermal resource in a fragmented land ownership situation.

2. 2006 court decision

Following a series of hearings in Auckland and Taupo, New Zealand, in 2005, the Environment Court of New Zealand ruled out the single operator system, which had been suggested by Environment Waikato. The court decision states that "limiting development to a single operator scenario is not the most appropriate way of providing for sustainable development of the Development Geothermal Systems" (*Decision No. A047/2006* 2006, p. 103). The Environment Court suggested that the likely issues related to multiple operations on an identical reservoir can be addressed by introducing comprehensive system management plan that address the following issues (*Decision No. A047/2006* 2006, p. 104):

1. Each single Development Geothermal System needs to be managed in an integrated manner (integrated system management)
2. Such integrated system management requires a package (regime) of objectives, policies and methods

Such an integrated system management regime for each development should include a system management plan, reservoir and subsidence modelling, reinjection/injection and discharge strategy including any cascade (secondary) users, multiple operator agreement(s), research and monitoring, peer review panel, review conditions and procedure, and introduction of a system liaison group/forum. (*Decision No. A047/2006* 2006, pp. 104, 105)

3. Unitisation

3.1. Background

The historical arrangement for the property rights of the resources depends on the negotiating parties and the distributional norms of society. These arrangements may have political impact on popular support and legitimacy of the governing party. Interested parties may push to gain the rights for those resources. The governing party may develop a plan to compensate those parties in forms of side payments (transfers) or restrictions on rights to be granted to others.

Since the discovery of petroleum in the United States in 1859, there has been serious common pool problem in the production of crude oil in some states. Different parties were competing for migratory oil lodged in subsurface reservoirs. "Under the common law rule of capture, private property rights to oil are assigned only upon extraction. ... For each of the firms on a reservoir, a strategy of dense-well drilling and rapid production allows it to drain oil from its neighbours and to take advantage of the low extraction costs that exist early in field development. In new, flush oil fields, subsurface pressures are sufficient to expel the oil without costly pumping or injection of water or natural gas into the reservoir to drive oil to the surface." (Libecap, 1989, p. 93) Rapid extraction by competing firms will reduce the surface storage and consequently oil pressure. Consequently, firms have to start using pumps sooner, which increase the cost of extraction. This is a common pool loss, which is the result of firms not cooperating with each other. A high volume of extraction in early stage of development can drive the oil price down which in future, makes it harder for investors to gain enough money for further investment. Many researchers recommend unitisation as the solution to the common pool problem,. Having one operator will reduce the rate of extraction and keep the market price at a reasonable level. It will also reduce the risk of need for extracting pumps to be used at an early stage, which reduces extraction costs. Despite the advantages of unitisation, it has not always been accepted by all parties involved in a single development. Involved parties may have concerns about the dividend share formula. Although the total gain of the production may be higher, the distribution of the share may not make all involved parties better off. Those who are more productive may lose as the result of unitisation. Prorationing is another alternative to prevent rent dissipation. "Prorationing could be adopted because it allowed for side payments through favourable production quotas to politically influential parties that were not possible with unitisation, even though unitisation offered larger aggregate returns." (Libecap, 1989, p. 114)

"Crude oil production historically has been characterised by too rapid extraction rates, overcapitalisation, and reduced oil recovery. The most complete solution to the common pool problem in oil production, unitisation, has been difficult to implement privately in a timely manner. Government policy, reflecting, in part, the political opposition to forced unitisation, has relied largely on prorationing, whereby production quotas are assigned to individual wells. Prorationing, though, has brought only limited gains relative to those possible under unitisation. With the incentive to drill that has existed under prorationing rules, as late as 1980, the United States had 88 percent of the world's oil wells, but only 14 percent of the world's oil production." (Libecap, 1989, p. 120)

Geothermal resources are different to oil because the resource is "continually being replenished by an on-going flow of heat from depth by conduction or by convection of water…. The resupply of the heat can be greater than 10% of the recoverable heat calculated from storage. Experience since then in geothermal systems such as Wairakei-Tauhara and Nesjavellir has demonstrated that in favourable situations recharge can supply a substantial proportion of the heat extracted and can extend the productive life of the resource." (Clotworthy et al, 2010)

3.2. Literature

Open access does not work well to sustain renewable resources. In a competitive situation the rent will go down to zero, which is better for consumers as more output will be generated at a lower price, but this may deplete the resource faster, as a higher quantity of input will be required for higher production. (Conrad, 1999) Therefore, a monopolistic model may work a lot better to ensure the sustainability of the resource. Anderson and Hill (1983, p. 111) review the situation in a farming environment and mention that "the size of the efficiency loss can be reduced, and thereby rents increased if farming effort is reduced". Cheung (1970, as cited in

Anderson & Hill, 1983, p.111) uses a fishery example to describe the situation as follow: "there exists incentives to fishermen to restrict the number of decision units who have access to the fishing right. That is, even if each decision unit is free to commit the amount of fishing effort, the 'rent' captured by each will be larger the smaller the number of decision units." The literature goes further in describing unitisation as the answer to the utilisation of a spatially linked renewable resource (Kaffine & Costello, 2011). In case of a geothermal resource, smaller rates of extraction will help to sustain the resource for a longer period of time as it allows the reservoir to recover (Clotworthy, Ussher, Lawless, & Randle, 2010).

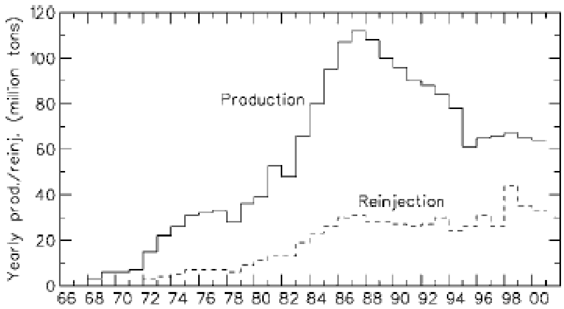
Allowing for private ownership based on the first come first served basis will lead to a race for ownership. Individuals may rush to start using the resource in order to win the race. They are willing to spend up to the expected rent to win the race. This may increase the cost of transaction, while parties could save on the transition cost if they could agree on the ownership. However, multiple access to the resource may lead to overdevelopment of the resource as parties try to maximise their gain. This may put too much pressure on the resource and deplete or damage it. Consequently, the reservoir might need years of no extraction to recover from the damager. In some cases it might never reach the original equilibrium (Boast, 1989, p. 9). Access to information and temperature/pressure control are the two issues associated with multiple access to geothermal reservoirs.

3.2.1. Information and unitisation

Although geothermal resources are often described as renewable, renewability depends on the size and timing of exploitation. Extraction and development of the resource generates information that enables study of reservoir behaviour and reaction to the resource development. It will also help to determine the new equilibrium with respect to the size of extraction and time that it takes to achieve the new equilibrium. It is suggested that the study should continue for 5 to 7 years to gain a better understanding of the reservoir. Therefore, a step by step development might be best practice for the use of a geothermal resource. Gaining information is a time consuming and costly task. It starts from identifying the resources and finding the equilibrium temperature and pressure of the resource to the behaviour of the resource on extraction. Although pressure can be partially controlled by injecting/re-injecting the brine back to the reservoir, the temperature response may almost be beyond human control (Gringarten, 1978, p. 302). Temperature depends on the conductivity of the hot rocks connected to the reservoir and also the permeability of the rock to the flow of the brine. Extracting the brine from a geothermal resource may drive the temperature down to a new equilibrium point, or the temperature may continue to fall to uneconomic values. Reaching a new equilibrium that can last for a long period of time is the most important task to achieve sustainable resource development. The new equilibrium can be predicted by using the existing techniques. Allowing multiple access may lead to a rush into further development. To stop the entry of competitors, the leading firm might decide to use the existing information to make development decision sooner than is desirable. The information may not necessarily be accurate if it is taken from the first couple of years of development.

3.2.2. Re-injection and unitisation

The second issue is related to the impact of extraction and re-injection on the temperature and the life of reservoir. Re-injection to the reservoir may be useful for maintaining the pressure and extending the life of the reservoir. In some cases fluid supply plays a crucial role in extending the life of the resource for electricity production. Although the heat flow has to be natural, the fluid supply can be artificial and can come through re-injection. The Geysers field in California of the USA began to decline in late 1980s because of lack of fluids (IGA, 2004). The figure below shows that an increase in the rate of re-injection helps to reduce the rate of decline in reservoir's temperature/pressure and eventually production level. This is particularly true for the vapour-dominated systems like Geysers. (Kaya et al, 2011)



Production and reinjection history of the Geysers geothermal field in California
Source: (Axelsson & Stefansson, 2003)

Gringarten (1978) evaluated reservoir lifetime and heat recovery factors in geothermal aquifers used for urban heating. He found that the life of the reservoir depends on the development scheme. He compared single and doublet production systems, and concluded that reinjection of heat depleted water enhances the heat recovery and increases the lifetime of the reservoir.

Not having access to the whole resource will reduce the efficiency of the utilisation. There is less space available for siting the production wells and reinjection wells. Less production wells means not being able to fully utilise the resource and closer re-injection wells mean less life expectation for the resource. Limited access to the land can limit the distance between the production and injection wells and therefore reduce the lifetime of the reservoir (Golabi & Scherer, 1981). Gringarten (1978, p. 302) mentions that:

> Reinjection maintains the reservoir's pressure, prevents subsidence, and insures an indefinite supply of water. It also permits the recovery of the heat contained in the rock, but as a result, it creates a zone of injected water around the injection well at a different temperature from that of the native water. That zone will grow with time, and will eventually reach the

production well. After breakthrough occurs, the water temperature is no longer constant at the production well and this may reduce drastically the efficiency of the operation.

He also concluded that "geothermal aquifer production should be unitised, as is already done in oil and gas reservoirs" (Gringarten, 1978, p. 297). He believes having multiple injection points close to each other will speed the cooling process of the reservoir and reduce the lifetime of the system and suggest that alternating injection and production wells will lead to greater reservoir lifetime. Gringarten (1978) identifies the reservoir's characteristics, distance between the production and injection wells, and extraction as the main factors contributing to the lifetime of the reservoir. This finding is similar to what Golabi and Scherer (1981) use in their work to find the optimised profit from the development of a geothermal reservoir for electricity generation. They also show that breakthrough time depends on the characteristics of the reservoir and the distance between the production and injection wells.

3. Model and results

Similar to the petroleum resources, the amount of usable resources in geothermal resources depends upon the time-path of production. In the case of oil, extraction will eventually reduce the pressure of the reservoir and increase the pumping cost. However, this problem can be addressed in geothermal reservoirs by re-injecting the brine back to the reservoir to maintain the pressure of the reservoir. However, re-injection may reduce the temperature of the reservoir. Therefore, the extraction rate will have negative effect on the temperature of the brine. This is in particularly true if the temperature recovery rate of the reservoir is low. The temperature recovery rate depends on the individual reservoir and the conductivity of the rocks to the source of the reservoir's heat (Blair & Cassel, 1979).

In general the characteristics of different reservoirs may vary significantly. Therefore, finding a production model that works for every individual resource may not be possible. However, all models share some general behaviour that can be used to develop a generic production model. A simple production model was adopted from Golabi and Scherer's (1981) work to simulate the optimisation problem. The model is to maximise the profit as follow:

$$\text{Max: } \Pi = R - C$$

Subject to:

1. $T_i \geq x$
2. $q, Q \geq 0$

The main profit function is shown as the difference between revenue generated by generating electricity. The production function is subject to the availability of brine at a given temperature, T_i, higher than a certain level ($T_i \geq x$). It is also assumed that production Q and extraction q are always larger or equal to zero. The production function has a direct relationship with the temperature and the amount of brine extracted from the reservoir. Cost has two components: fixed and variable.

It is assumed that two pieces of land a and b are owned by two firms A and B respectively. It is also assumed that land a is larger than land b. Therefore, firm B has to re-inject the brine closer to the production well. The colder re-injected brine will take some time to reach the production well. However, the lag period is assumed to be shorter for firm B with smaller piece of land. The information to run the model is taken from one of the existing New Zealand developments, Rotokawa (Grant, 2007; Reeve, 2007).

The first model assumes that firm A owns both blocks of land and can chose the best place for the production and re-injection wells. The model is used to run a 100MW plant on a reservoir, as the stage one project. Results show that there is a temperature drop through the life of the project, as expected. In stage two, the size of the plant was doubled to produce 200MW of electricity. The stage two results show a further drop in the temperature, as expected. It also shows that the profit is not double that of stage one. This is directly linked to the larger rate of decline in the temperature of the brine extracted from the reservoir, as the temperature will have a direct impact on the production model.

The second model uses the original assumption of the two firms and two different areas of land. The total production would be 200MW with 100MW produced by each firm, A and B. The smaller land area for firm B will cause the re-injected brine to reach the production wells in a shorter time. The results show that the temperature drops at a higher rate than when the 200MW plant was owned by a single owner with access to the entire reservoir. The higher temperature drop rate means faster depletion of the reservoir. The result also shows lower total profit from the development of the two projects. This will eventually mean lower current return from the resource and also less value for future generations. The results are in line with previous studies and raise concerns about multiple access geothermal developments. It shows that even though the property rights are well defined, the rights of individual landowners may work against the sustainability of the reservoir and the profitability of the project. In general the total gain from the development of the project will be less for the local community.

5. Conclusion

It is widely accepted that open access competition does not lead to sustainable use of a renewable resource. Unitisation has been suggested as an answer to issues related to open access. Although geothermal resources are often described as renewable, renewability depends on the size and timing of exploitation, distance between the production and re-injection wells, and the heat recovery factor. A production model was used to study and compare the outcome of a 200MW development with single ownership and access to the entire reservoir to a similar development shared by two owners with partial access to the reservoir. Data from the Rotokawa reservoir in New Zealand were used in the optimisation model. This study found that, in a fragmented land ownership system with multiple access to the resource, lack of available space may lead to faster depletion and lower economic benefits.

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