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Role of royalties in sustainable geothermal energy development

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HIGHLIGHTS

- Geothermal reservoirs can provide a sustainable flow of energy.
- Policy design is critical for renewable supply of energy.
- Sustainable use depends on property rights, access and use rates.
- Fiscal policy impacts use and provides revenue for government

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ABSTRACT

Experience with geothermal development for electricity production has shown that use is not sustainable if heat from the reservoir is extracted too rapidly. Examples of unsustainable development are given. Policy aimed at achieving sustainable development at the very least should encompass conditions governing access to reservoirs, the rate at which thermal energy is extracted, monitoring, and re-injection of fluids. An economic model illustrates the application of fiscal instruments to geothermal development for electricity generation. Ad valorem royalties are shown to encourage utilisation of the resource in a more sustainable manner. A variable ad valorem royalty, based on the ratio of the current and original temperature shows a significant change in investment planning, with slower depletion, compared to the application of a non-variable ad valorem royalty.

1. Introduction

Over the period 1990 through 2013 renewable sources of electricity contributed, on average, 73% of New Zealand's electricity supply. In 2013, 41,467 GWh were generated; hydro supplied 55%, geothermal 14% and wind 5%; natural gas and, to a limited extent, coal accounted for the balance (Ministry of Business, Innovation and Employment, 2013). The contribution of geothermal energy to electricity supply has approximately doubled over the last 15 years. As a base-load supplier to the electricity market, geothermal has an advantage over other renewable sources that are characterised by intermittent supply viz. wind, solar, and hydro. In addition to offering a secure and reliable supply of electricity investment in geothermal energy has an added advantage of relatively low carbon emissions. Climate change policies, aimed at pricing greenhouse gas emissions, make renewable energy such as geothermal more competitive. A survey by the International Geothermal Association (2002) reports a range of CO_2 emission rates of 10–400 g/kWh; approximately 10% of oil and coal fired plants and 30% of gas-fired combined cycle plants. Emissions of CO_2 from New Zealand geothermal plants average 100 g/kWh (NZGA, 2014).

New Zealand has relied on hydro resources to generate electricity for well over 100 years. In the mid-1940 s development was hampered by shortages of imported components and supply was unable to cope with the increase in demand. Electricity rationing was first imposed in 1947 and the frequency of shortages increased through the mid-1950s. In 1956 the government decided to investigate the feasibility of a submarine cable to link the North and South Islands, the latter being a source of undeveloped hydro sites. Government also turned its attention to developing other sources of electricity, including the development of geothermal sources. The first geothermal electricity generating plant was commissioned in 1958; the second in the world and the first to exploit a wet resource. Wet steam fields contain water under pressure, which when brought to the surface some of the water flashes into steam that is used to drive electricity generating turbines. Today, six fields are used for electricity generation. Development has provided a secure source of supply and an opportunity for Maori to participate in, and benefit from, commercial

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development.

Although geothermal resources are usually considered a renewable source of energy, the degree of renewability depends on the rate of extraction and heat regeneration. Excessive extraction of heat can speed depletion, reduce reservoir productivity, and in some situations lead to subsidence. In the absence of policies aimed at promoting sustainable use of the reservoir into the foreseeable future it is quite possible that the thermal properties of the resource are reduced to a level that cannot support electricity generation.

The literature on the economics of stock resource depletion is well developed. Conditions for optimal depletion are provided by Hotelling (1931) and thoroughly explored in the foundational work of Dasgupta and Heal (1979). Recent focus has been on the design and application of fiscal regimes in extractive industries. Resource taxes and royalties are used by many governments to collect a share of the revenue or profit associated with using government owned or controlled natural resources (Boadway and Keen, 2014). The International Monetary Fund (IMF, 2012) has highlighted the importance of design and implementation of fiscal regimes to realising revenue potential. While fiscal instruments can be used effectively to influence depletion rates it would appear that revenue generation is the primary interest of governments throughout the world.

The issue of resource pricing is also relevant to the efficient supply of energy. The case for a comprehensive approach to efficient pricing can be illustrated as follows. Setting aside unpriced externalities, electricity generated from the use of an unpriced resource can be delivered to market at a price lower than electricity generated from use of a resource that is priced. This, of course, favours the production of electricity from unpriced resources. The issue of efficient resource pricing is complex and beyond the scope of this paper. With a few exceptions, noted in the literature review that follows, the use of geothermal resources to generate electricity is unpriced. Sustainable use of geothermal resources is particularly relevant given that many countries have adopted renewable energy strategies. To date, the analysis of how different royalty regimes can contribute to sustainable use has not been studied.

1.1. Renewability

Geothermal areas are commonly located close to the edges of continental plates. Energy is derived from heat generated and stored in the mantle and core of the earth. Deep faults allow water to flow to heat sources in the crust and the ascending hot water forms a geothermal reservoir that can reach temperatures of 350 °C or more. A geothermal system is therefore a combination of a heat source, a reservoir and fluid that transfers the heat (Dickson and Fanelli, 2004). Systems with temperatures higher than 150 °C can be used for large-scale commercial electricity generation.

Geothermal resources differ from stock resources, such as oil and gas, because the resource is continually being replenished by an ongoing flow of heat from depth. However, development can affect the resource in several ways including, but not limited to: cooling of the reservoir; subsidence; reduction of fluid resulting in changes to surface features and habitats; hydrothermal eruptions; interference with existing takes; and changes in the location of the heat and fluid. Although some geothermal resources have been over-exploited and heat extraction has had to be reduced, no geothermal field in New Zealand has yet to be exhausted. Experience with re-injecting spent fluids has demonstrated that recharge can extend the productive life of the resource (Clotworthy et al., 2010). Surface discharge of geothermal fluid may lead to contamination of ground water, cooling of the geothermal reservoir, and change to habitats (Luketina, 2011).

Information about a reservoir is never perfect. Although initial information is gathered through exploratory drilling and testing, monitoring the real response to extraction will reveal actual behaviour of the reservoir. A typical geothermal operation will collect information on the volume, geometry and boundary conditions of the reservoir; properties of the reservoir rocks, such as permeability, porosity, heat capacity and heat conductivity; and, temperature and pressure distribution (Axelsson, 2008). It may be years before the reservoir's real behaviour is known (Axelsson, 2010). Where feasible, adjustments to the rate of extraction further allow for a better understanding of the reservoir's behaviour.

Bromley et al. (2006) state that with appropriate management, a geothermal system can be utilised over a long period (~100 years), then retired for recovery. However, excessive production driven by a commercial imperative to obtain quick return on investment will result in depletion (Rybach and Mongillo, 2006; Rybach, 2010; Rybach et al., 2000). During the recovery period both temperature and pressure increase, although temperature recovery is always slower than the pressure recovery. It may take an indefinite amount of time for the reservoir to reach its original state (Rybach, 2007). According to O'Sullivan and Mannington (2005) it could take the Wairakei geothermal reservoir in New Zealand 300 years to recover to its pre-production temperature state after 100 years of production.

The Geysers, Rotorua and Ohaaki, are examples of over-exploitation, resulting in shortened commercial life. The Geysers Geothermal Field, a field of steaming fumaroles located 115 km north of San Francisco in California, was predicted to produce 3000 MW of electricity by 1990. However, development stopped at around 2000 MW because developers came to realise that the field was running dry and steam pressure had reduced in the wells. The resource was overloaded and had depleted faster than expected, due to lack of sufficient water to produce steam. Generation went down to about half and developers started to condense and re-inject some of the used steam back, along with other sources of water, into the ground to help the reservoir recover (Axelsson, 2010).

Rotorua in New Zealand is an example of excessive use of a geothermal resource in the 1970s and 1980s when geothermal heating systems were encouraged. Households accessed the geothermal resource under their properties for heating. Open access and the relative low price of geothermal sourced heating led to excessive extraction and eventually the reservoir's pressure dropped, leading to subsidence and damage to tourist attractions in the geothermal area of Rotorua (O'Shaughnessy, 2000; Scott and Cody, 2000).

Ohaaki in New Zealand is another case where excessive extraction led to lower productivity in a short period of time. The plant was commissioned in 1989 with a capacity of 114 MWe. However, field limitations led to production being reduced to as low as 30 MWe. Further investment, including drilling new wells, helped to increase the production level to 60 MWe but to date the original level has not been restored. There have also been significant environmental effects including subsidence leading to flooding (NZGA, 2012).

This paper provides an overview of the features of geothermal resources, governance of access and policies that could contribute to enhancing availability over a relatively long period. Section 1 provided an overview of the resource and reviews issues around sustainability. Section 2 outlines the approach used to investigate the challenges of policy and provides an overview of international experience with rent taxes and royalties. An economic model is used to experiment with different forms of royalties that can be applied to geothermal developments for electricity generation. Results are presented in Section 3 and discussed in Section 4. The paper concludes with a discussion of policy implications and