CAN GEOTHERMAL REGULATION ENHANCE (TECHNICAL) INNOVATION – EVIDENCE AND CASE STUDIES FROM NZ AND INDONESIA

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ABSTRACT

Indonesia and New Zealand offer a good comparison, since both countries have a long history of large scale geothermal development of high temperature geothermal resources.

When considering the types of plants historically installed, in New Zealand there was a wide range of technologies adopted. In Indonesia there is virtually only installation of single-flash condensing steam turbines (mainly in 55 MWe units). This paper contends that this difference can be in large part explained by the type of regulations and policies (resource access, electricity market; and environmental policy) that were in place.

We conclude that regulation and market settings can enhance or inhibit innovative solutions in (geothermal) energy projects and derive some potential lessons for NZ and Indonesia. In neither case are the adopted solutions always the most technically or economically efficient. There may be good policy reasons for the choices adopted but it is as well to make these explicit. The same general principles will apply to other countries as well.

1. INTRODUCTION

There are several technological pathways available to convert geothermal energy to electricity, each with its pros and cons in terms of efficiency, capital and operating cost and environmental impacts. Matching the power plant to the resource and optimizing financial return over the project life involve well understood principles that affect the choice of technology. Financing considerations may also play a role. What is perhaps less often explicitly discussed are the roles of the regulatory environment and power market in the choice of technology. This paper explores those connections by contrasting historical technology choices in Indonesia and New Zealand and some of the reasons behind them.

Indonesia and New Zealand offer a good comparison, since both countries have a long history of large scale geothermal development of high temperature geothermal resources. New Zealand started geothermal generation in 1958 and now has about 1000 MW installed. Indonesia started its geothermal generation in the 1970s, and is now the 3rd largest geothermal producer in the world at around 1400 MW capacity, with plans to add 6000 to 8,000 MW of geothermal generation by 2025. There is also a long history of technical cooperation, so both countries can be considered to have had access to similar expertise and technology. In both countries there is a history of mainly government activity in the industry initially, followed by increasing privatization and de-regulation with time, though New Zealand has now gone further down that path than Indonesia has.

2. RESOURCE CHARACTERISTICS

Although the main focus of this paper is on the influence of regulatory and market factors, there are some differences in resource types between Indonesia and New Zealand which need to be acknowledged.

The high temperature resources of New Zealand are located in a “continental” setting (Henley and Ellis, 1983) and with the exception of Ngawha are within a major geological rift, though the undeveloped resources of Tokaanu and Tongariro are also associated with andesitic strato-volcanoes and so are more similar to the Indonesia resources.

The pertinent resource features in New Zealand are as follows:

- Shallow resources with high temperatures near surface
- Large boiling springs and geysers are common
- There are some steam zones but the resources are mainly liquid dominated
- There is generally easy access
- They are well connected to groundwater
- The upper parts are predominantly hosted in rhyolitic clastic formations with high lateral permeability.

The resources of Indonesia are in more diverse settings, but those that have been developed so far on a large scale, in Java and Sulawesi, are within an “island arc” setting (Henley and Ellis, 1983). Some of the large undeveloped resources in Sumatra within pull-part tectonic basins are more similar to those in the Taupo Volcanic Zone of New Zealand, but this paper concentrates on those that have already been developed.

The relevant resource features in Indonesia are as follows:

- They are just as hot as in NZ, but they are deeper resources and so more expensive to develop
- Large boiling springs are less common
- There are several dry or near-dry steam resources
- They are often in mountainous areas with more difficult access and so are more expensive to develop
- They are not so well connected to groundwater because they are deeper
- They are predominantly hosted in andesitic formations with high local permeability (hence individual wells are as productive as in NZ) but are not so well connected across the whole reservoir

Note these comments apply mainly to the resources already developed in Java: as more development occurs in Sumatra and Sulawesi, some resources there are more similar to NZ ones.

3. RESOURCE & ENVIRONMENTAL REGULATIONS AND ELECTRICITY MARKETS

3.1 New Zealand

3.1.1 Electricity market & renewable support policies

New Zealand originally had a monopoly market, with all generation, transmission and retail government controlled. Originally all geothermal development was also government controlled. In the 1980s, successive governments embarked on a radical restructuring and liberalization of the economy including the electricity industry. Between 1986 (State-Owned Enterprises Act) and 2001, the sector was gradually separated into a regulated part for monopoly transmission and distribution lines companies, while generation and retail (including to small, residential end-users) became markets open to full competition. In 1996 the New Zealand Electricity Market (NZEM) was created and started to trade all wholesale electricity (gross pool) between generators and retailers over a full set of pricing nodes (255 at present). In practice, over the years, generators and retailers integrated to manage risks, resulting in 5 integrated 'gentailers' covering about 95% of the market. It is now largely de-regulated and the generators are a mixture of SOEs and IPPs. There is a mandated separation of wholesale purchase, transmission and retailing. Prices are contestable on a half-hour spot market, plus some longer hedge contracts

New Zealand consists of two major islands. The electricity grids between both islands are interconnected. In 2015, the total installed capacity was 9,603 MW and the total energy generation was 42,861 GWh pa (MBIE, 2015). The alternative sources of generation were historically mainly hydro and gas, but with the gas becoming scarcer and more expensive in the 2000s, that led to an upsurge in new geothermal in the past two decades.

Electricity demand has grown quite steadily over the years with 1.5 – 2% over the previous decades, with previous expectations of 1 - 1.5% growth continuing until 2025. However, since the global financial crisis in 2008, demand growth has actually been virtually flat, which has created a current oversupply of generation. Many planned generation investments (including geothermal) have recently been put on hold until demand picks up.

New Zealand generates a high proportion of electricity from renewable resources. The government has set itself an 'aspirational' target of 90% renewable generation by 2025. In 2015, renewable energy accounted for 80.7% (and growing) of generation, of which more than 50% is generated from hydro-electric sources, and 17.2% from geothermal sources, replacing the coal and gas-fired generation. The bulk of hydro-electric generation is heavily dependent on variable hydro inflows. Reliable baseload and back-up generation (like coal, gas and geothermal) are therefore important to the security of the system. Wind generation has also slowly been increasing to 5% of annual generation. (MBIE, 2015).

Despite the aspirational targets, New Zealand in practice has very limited support policies for renewable energy. In 2008 an Emissions Trading Scheme (ETS) was introduced, but successive governments have weakened the scheme and developments in international climate change negotiations have resulted in extremely low prices providing little support for renewables. Recently, after COP Paris (November 2015), carbon prices have started rising again and are topping NZ$ 10/tonne again. A recent government review has strengthened the ETS.

General wholesale electricity prices are relatively low (but volatile), averaging around NZ$ 80-90/MWh (MBIE, 2015), but due to the excellent geothermal resources, located in the Central North Island close to demand and transmission, geothermal projects are among the most competitive, with new generation projects at 80-100 NZ$/MWh. At the same time, older existing fossil fuel generation projects are under pressure to close or reduce operation: two 250 MW coal-fired units have already been mothballed. Further closures of thermal plant occurred in 2015, opening up the way for new investments in (geothermal and wind) generation.

The result is that wholesale electricity prices (but not retail) are relatively low on a world scale. Geothermal has to, and does, directly compete successfully on price with other sources of mainly renewable generation such as wind.

3.1.2 Resource ownership and access.

Originally all geothermal development was government controlled. There was a very extensive exploration programme including 20 years of government-funded drilling. This has left a huge legacy of resource data, though access to it can be problematic and/or expensive. In many cases, projects such as Mokai which were later developed by IPPs were already substantially de-risked through this government exploration and drilling programme. Under the current regime the residual resource risk is now on the developers.

In New Zealand it is necessary to distinguish between the pre-Resource Management Act (RMA 1991) and the current situation as the controlling legislation changed markedly with the introduction of the RMA. Geothermal resource allocation, planning issues and environmental issues were originally under separate legislation. Now, uniquely in the world, resource allocation and environmental issues are both under the RMA.

In New Zealand, legal ownership of minerals, water and geothermal resources are treated as separate from land ownership, i.e. the landowner is not the automatic owner of the resources on or under the land. Geothermal resources were first regulated through the Geothermal Energy Act 1953 and the Geothermal Energy Regulations 1961. In 1967 the Water and Soil Conservation Act (WSCA) introduced a system of water rights (including geothermal water).

The RMA is now the principal legislation controlling the use of geothermal resources in New Zealand, replacing most previous acts. It introduced a similar structure of resource consents to the WSCA-1967, but covering a wider area of 'impacts' including resource off-take and disposal/re-injection, emissions to air and water, and ecosystem and community impacts. By maintaining the main structure of the WSCA, geothermal energy in New Zealand is effectively regulated as a *water resource*, with the main consenting criteria defined in tonnes of water/liquid volume per day/year (rather than GJ or MW). Geothermal regulation in New Zealand is therefore more water-resource than energy based.

In practice, the RMA (1991) vests the sustainable management of the geothermal resources (regardless of exact resource ownership) in regional authorities, under a requirement for a resource consent to use (exploit) a natural resource with numerous clauses and conditions to assure sustainable management of the resource. In the case of geothermal, the resources and therefore their management are mainly concentrated in the regions of Waikato (WRC) and Bay of Plenty (BOPRC).

There is no specific, legal requirement to return any money to the local community, though most developers are actively engaged in supporting local activities. A geothermal project developer will need to negotiate and gain permission from the landowner(s) above the resource, who control the physical access to the geothermal resources. Negotiations generally result in a lease agreement or some other payment, or a whole or partial ownership/co-investment in the project. Many geothermal projects are sited on land owned by Maori groups, reinforcing their role in NZ geothermal development.

3.1.3 Regulation of Environmental Impacts

The RMA is the main Act defining the management of both the geothermal resource use and environmental impacts in New Zealand. The RMA is considered a "meta policy" instructing regional and local authorities to take control of their own objectives, policies, rules and any other method to manage their resources (Dickie, 2005). These policies are guided by National Policy Statements (NPS) and the cumulative case law confirmed by the hierarchical Environment Court and High Court decisions. Hence effectively guidelines have generally been developed on a case-by-case basis.

Regional Councils and District/City Councils have slightly different areas of jurisdiction (the latter for instance largely cover noise and land use impacts, while the former cover wider, regional impacts on water- and air-sheds – more details can be found in Lawless et al, 2016, Campen and Rai, 2015). In practice applications for resource consent are combined and submitted as one application and hearings for all aspects are usually combined for a 'one-stop-process'.

Protection of natural geothermal features including their cultural significance is now regarded as important, though it was not given much prominence in earlier times especially prior to the RMA. About half of NZ's high temperature resources are now protected from development to a greater or lesser degree, and effects on thermal features and ecosystems is the main reason for those classifications (Lawless and Lovelock, 2001). This can extend to effects through possible (but largely unproven) interconnections between fields, as in the case of the Ngatamariki and Orakei Korako fields discussed below, and Reporoa which has so far been inhibited from development because of a possible connection to the adjacent protected Waiotapu field. Thinking on this matter has no doubt been affected by the demonstrated connection between the developed Wairakei and Tauhara fields which have separate hot upflows but which have a hydrological pressure connection.

Some of NZ's actual environment standards have been quite lax compared to other countries, especially historically. Discharge of geothermal fluid to waterways and ground soakage are not necessarily prohibited. Relatively high levels of H_2S discharge to air are permitted, mainly in recognition of high natural levels in many locations. There is no requirement for chemical mitigation of air discharges, hence direct contact condensers can be used (in contrast to the USA for example). Reinjection is not mandatory, though it has been applied to all recently built developments on a case by case basis.

The environmental effects of geothermal development in NZ have been significant, especially for the early developments which were the first liquid dominated resources in the world to be developed on a large scale, without reinjection and where the possible consequences were not well understood. Especially at Wairakei, but also elsewhere, there have been extensive effects on thermal features and specialized ecosystems, locally extreme induced subsidence, induced hydrothermal eruptions and significant degradation of the Waikato and Tarawera rivers. Avoiding such effects in the future has coloured the thinking on subsequent developments and hence on the selection of technology.

3.2. Indonesia

3.2.1 Electricity Market & Renewables Support

Indonesia has a monopoly power market, with a single agency (PLN) for wholesale purchase, transmission and retailing. The generators are a mixture of IPPs and SOEs, including PLN. Wholesale power prices are regulated on a project by project basis. There are specific ceiling prices for geothermal which effectively is an incentive versus e.g. coal, and Indonesia has committed to increasing the amount of renewable generation. Retail prices are subsidised, which creates a contradictory situation whereby PLN can be reluctant to accept new generation as it may cost them money if they cannot recover the additional cost through their subsidy from Ministry of Finance.

The alternative sources are mainly (cheap) coal on the main grids and oil/diesel in remote locations. Gas is used but there is an incentive to reserve it for export.

The electricity sector in Indonesia is regulated by Act No.15/1985 "Electricity" as amended by Act No.30/2009 "Electricity"; Government Regulation No.10/1985 "Electricity" as amended by the Government Regulation (GR) No.3/2005, GR No.12/2012 and GR No.23/2014; and MEMR Ministry Decree No.9/2005 and No.10/2005, MEMR Decree No.28/2012 as amended by MEMR Decree No.7/2016. MEMR through the Directorate General of Electricity (DGE) is mainly responsible to manage and develop the electricity policy and regulation. One of DGE's responsibilities is to formulate the country's electricity planning in order to meet the electricity demand in a sustainable and reliable way. Furthermore, its product is the National Electricity General Planning (RUKN) which is a complete and integrated guideline in the electricity sector, consisting of the national electricity supply and demand outlook, electricity project financing and investment, primary energy resources utilization, and the renewable energy sources for power generation (Jati, 2015; Nazif, 2015).

PLN is the only institution in Indonesia that delivers electricity to all people in the country. Moreover, PLN (and its subsidiary companies) generate electricity from their own power plants, and it has a role as the electricity single buyer from IPPs. All the electricity generation is planned in the PLN's RUPTL (General Plan of Electricity Supply) for a ten year programme.

3.2.2 Resource ownership and access

In Indonesia, as in most countries, geothermal resource allocation and environmental issues are handled separately. Resource allocation was originally and is now by central government. There was a period when it was devolved to regional governments, but that proved to be largely not effective. There are however what are effectively royalties (by another name) collected and allocation of money to communities and local government is mandatory. Land-owners have little influence on resource allocation though they get compensation for land which is used.

Resource allocation is through competitive bidding of one sort or another. The regulations are currently under review but for most of the historical period which is the subject of this paper power price has been the main determinant. Central government decides which resources are tendered and for what project size. Allocation is by output (MW), not fluid quantity as in NZ. Competing generation on the same resource is not permitted. Tourism and direct use are very minor compared to NZ.

Originally all geothermal exploration and development was government controlled. Compared to NZ, there was a much less intensive exploration drilling programme, and little government-funded drilling after the early projects. Resource data can be scanty and hard to obtain. All resource risk is currently on the developers, which inevitably increases costs. There are however actions in train to improve that situation with assistance from both the World Bank and the NZ government along with other donors and the Indonesian government.

The outcomes are that wholesale prices (but not retail), are generally higher than in NZ though not high compared to some other countries. Geothermal can only compete successfully on the main grids with other sources where it is incentivized through the tariff structure. In remote locations it may be the lowest generation cost option compared to diesel, provided the load is sufficient to justify drilling

3.2.3 Regulation of Environmental Impacts

Environmental issues in Indonesia have more reference to national standards than in New Zealand. Many of the developments in Indonesia have been funded by multi-lateral funding agencies such as World Bank and ADB, who also have their own standards which must be adhered to. Sustainability and efficient resource use are not apparently considered major issues by the Indonesian government. Protection of natural features is not usually considered important, and they generally do not have much perceived cultural significance (other than in Bali). No areas are protected from development on the basis of their thermal activity per se, though access to some areas is limited by their being in national parks or other protected ecosystems

Some environment standards are more rigorous than in NZ, e.g. discharge of geothermal fluid to waterways and ground soakage are not permitted. Reinjection, including of well-test fluids, is mandatory.

Environmental effects in Indonesia have generally been less than in NZ, in part because the resources tend to be deeper and not as well connected to the shallow aquifers, but also probably because of universal reinjection. There have been limited effects on thermal features and limited induced subsidence but not sufficient to case damage. There have been no definitely induced hydrothermal eruptions, though there have been some severe natural ones e.g. at Dieng (Le Guern et al. 1982). There has been no degradation of rivers. There have been minor direct effects on vegetation through well discharges. The most significant effects have probably been indirect: creating access to previously-pristine forest areas so facilitating forest clearance and habitat destruction by parties other than the geothermal developers themselves.

4. BRIEF DESCRIPTION OF DIFFERENT GEOTHERMAL TECHNOLOGIES

Most large scale geothermal power plants in the world today use steam turbines, either back pressure or condensing, binary (ORC) plants or some combination thereof. Wells may be pumped or naturally flowing and either utilize single phase or two phase fluid which is usually separated into steam and brine, but since all resources developed on a large scale in Indonesia and New Zealand are high temperature, all wells are self-flowing and separators are used except for where wells produce dry steam.

The relevant characteristics of the power plant types are summarized in Table 1 below.

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	Size/ modularity	Capital Costs	Thermo-dynamic Efficiency	Water Conser-vation	Other remarks
Back-pressure Steam Turbine	Mid-range	Cheapest capital cost	Least efficient when stand-alone	Mid-range	Most applicable at remote locations (e.g. single well) and/or early stage resource testing
Condensing Steam Turbine	Largest turbines and economies of scale	More complex, next cheapest per MW	Efficient in terms of steam usage, but require high grade resources	Lower, depending on cooling	On-going output and efficiency Improvements through dual and triple flash
Binary Plants	Small and modular	More expensive per MW,	Not very efficient perse, but can make use of lower grade resources	High	Usable as modular, staged deployment and as well-head generators
Combinations	Depends on combination; generally larger	Most complex and expensive	Use of binary plants on exit brine of steam turbines can significantly increase efficiency	High	Binary plants are being added at the back of existing plants; even better is include from design stage

Table 1: Overview of Geothermal Generation Technologies

5. TECHNOLOGY CHOICES RESULTING

5.1. Indonesia

In Indonesia there is virtually only installation of single-flash/single entry condensing steam turbines, mainly in 55 MW units with the notable exception of Wayang Windu with 2 x110 MWe units, some earlier projects with smaller units, and a few such as Lahendong where the size of the grid has likewise dictated smaller units. There have been a few small back-pressure units installed, mainly as individual wellhead units for temporary use. There is a notable lack of binary units except for one at Lahendong which was not from a mainstream manufacturer and should be regarded as more or less experimental. All except the back pressure and binary plants use evaporative cooling towers. Reinjection of all fluid that is not evaporated is universal.

One obvious reason for the technology used in Indonesia is the predominance of dry steam resources amongst those developed so far. Single-flash condensing steam turbines are very suitable for dry steam, and cannot use bottoming brine binary plants, though they could in theory use binary units as condensers, albeit with less efficiency than with direct contact condensers. This factor will not apply as much in the future, as there are not many promising, undeveloped dry steam resources remaining.

The lack of available large rivers near the projects also favours evaporative cooling rather than Wairakei-type direct contact condensing and discharge, which would not be environmentally permitted anyway.

The selection has also been influenced by the market and regulatory factors. From the regulatory perspective, there is no particular incentive to conserve and return condensate to the reservoir, which favours the use of evaporative cooling over air cooling. There is no strong regulatory importance placed on resource sustainability, nor any need other than public safety to avoid surface effects, which likewise does not promote full reinjection of condensate.

There has also been an abundance of high-quality resources offered for tender, and no competition with other developers within those resources.

The drivers then become economic: how to get the required MW as cheaply as possible, with no limit on fluid take. That is exacerbated by relatively high resource access costs in some cases and, until recently at least, relatively low regulated power prices. It is not surprising therefore that developers have chosen the most cost effective solution (at least in terms of capital cost per MW) of water-cooled, single-flash steam turbines.

Two factors which appear illogical to the outside observer are the continued use of 55 MW units even for large projects up to 220 MW, and the lack of bottoming binary plant.

In some cases, projects are constrained to smaller units by grid considerations. But in other cases, larger turbines could have been used (e.g. at Ulubelu stage 1 and 2, 1 x 110 MW rather than 2 x 55 MW), with a considerable cost saving, but have not, and official published development plans still seem to be based around 55 MW blocks.

The reasons for this are not entirely clear. To some extent it appears to be conservatism by the authors when preparing the RUPTL, at a time when they have very little knowledge of the actual available capacity of the resource. Anecdotally it is also driven by inflexible PPAs and the difficulties of re-negotiating them when the number and size of units is pre-specified, in some cases even before drilling.

The lack of binary bottoming plants was addressed by World Bank (2015), who estimated that in excess of 400 MW of bottoming binary plant could either be retrofitted to existing projects or built into new projects which are under development by 2020.

Some of the reasons for a lack of bottoming binary plants are thought to be similar to those affecting unit size: conservatism and inflexible PPAs. In this case conservatism also probably derives from a lack of operating experience in liquid-dominated resources – apart from the Chevron-owned project at Gunung Salak, most of the early large projects were based on dry steam or very high enthalpy resources. Thus despite the long history of geothermal development in Indonesia there is a lack of experience in managing large developments on liquid dominated resources. There may therefore be an unrealistic level of concern about adverse reservoir effects of the additional cooling which will occur with bottoming binary plants. There is also a lack of experience in chemical inhibition of silica deposition.

There may also have been an economic factor; binary power plants have a higher capital cost per MW installed (though this is offset by the lack of need for additional wells nor much extra piping), and as long as there appeared to be a continuous supply of high quality resources on offer, but with relatively low power prices, developers have understandably chosen to pursue least cost options.

New regulations are currently being drafted which hopefully will introduce more flexibility to the sector and address both of these issues.

5.2. New Zealand

The range of geothermal technologies used in New Zealand is much wider than in Indonesia. The choice of technology in New Zealand has been affected by a number of factors:

- A very early phase where the technology was to some extent experimental and environmental consequences were not taken into account to any significant degree, albeit because they were largely unknown.
- A gradually increasing awareness of environmental effects, reinforced by the RMA through the adoption of sustainable management as a guiding principle, including management of thermal features and ecosystems. The response has been to adopt more reinjection including over 100% injection at Ngawha, and in the case of Ngatamariki to select air cooled plant to conserve condensate for injection. In that case perceived possible environmental effects included those on an adjacent protected field as well as the Ngatamariki field itself. There has however also been persistence of earlier environmentally undesirable practices such as discharge to waterways at Wairakei and Kawerau, which could be considered inconsistent.
- The issuance of consents on the basis of fluid quantities rather than MW output has led to the use of a variety of energy-efficient plants with multi-stage flashing (whether to multi-entry steam turbines or binary plant in the same or separate ownership), in an effort to extract the maximum MW from a limited amount of

fluid. That in turn has led to the need to adopt chemical inhibition of silica deposition.

- In the case of Poihipi, a much larger power plant was selected than could be kept in base load operation by the amount of steam available per day under the resource consent. The strategy was to take advantage of the higher day-time spot market power prices and only operate it for part of the day.

The reasons for the selection have changed over time so it is best to summarize the developments from a historical perspective as below. MW figures given below are peak installed MW, in some case plants were later de-rated. Dates are the date of commissioning of the *first* stage of the project.

Wairakei (192 MW, installed 1958). This plant was originally designed to provide heavy water for the UK nuclear programme, which constrained the design. It was also somewhat experimental as it was the first large scale development of a liquid dominated resource world-wide. It is fair to say that not much attention was originally paid to possible environmental impacts or resource sustainability. It had a triple flash system using a combination of multiple small back pressure and condensing steam turbines. It used the adjacent Waikato river for direct contact cooling and discharged the condensate to the river (and still in part does) which is unique in the world. This combination of design elements is unlikely ever to be duplicated, but yielded a system which was quite thermodynamically efficient even compared to more modern plant. There was no brine reinjection until 1999, separated brine was and in part still is discharged to the river. There were significant environmental effects as described above.

Kawerau (40 MW equivalent, 1966). This plant was principally for direct use, so the technology was driven by direct use needs. It incorporated a back pressure steam turbine for power generation. There was no brine reinjection; it discharged brine to the Tarawera River. There were some environmental effects but not as severe as Wairakei, as it was a smaller take on probably a larger resource.

Ohaaki (112 MW, 1989). This had two twin-flash condensing steam turbines, plus use of the front-end back pressure units from Wairakei, which had been decommissioned when reservoir pressures there fell. Slightly more attention was paid to environmental issues. It adopted brine reinjection, though eventually mainly outside the field. There was no discharge to the river apart from well testing (but that was huge, over a much extended period when project development did not proceed under the then government power development programme) and topping up an original thermal pool. It used a natural draft cooling tower, because of concerns over plant efficiency impacts of using large mechanical draft cooling towers. There were some environmental effects but not quite as severe as Wairakei, probably mainly because of the smaller scale and partial reinjection. Rapid and severe reservoir effects have led to persistent under-performance of the power plant.

Kawerau binaries (total 39 MW from 1993). Several pure bottoming binaries have been retrofitted to extract energy from Kawerau brine. They are air cooled. There was not much choice in the technology to adopt for these, so the only interesting aspect from the present perspective is that they are in a variety of separate ownerships from the main plant. This had the effect of allowing some smaller investors to enter the market.

Poihipi (55 MW, 1996). This was the first IPP/RMA project in NZ. It originally tapped only a dry steam zone at Wairakei. It uses a single stage condensing steam turbine, bought as surplus (but unused) from The Geysers in the USA. The choice was influenced by availability of a specific very cheap second hand plant. It has evaporative cooling towers but otherwise adopts full reinjection of condensate (minus evaporation). The choice and size of plant was influenced by getting the maximum MW for a very limited defined quantity of fluid per day, as it competes for the resource with the Wairakei plant. Potential environmental effects were also a major factor leading to the limited permitted fluid take, though in fact only very minor environmental effects can be ascribed to this operation. When it was in separate ownership from Wairakei (it has since been sold to Contact Energy who operate Wairakei), it ran in a load-following mode, only 12 hours/day, to take advantage of the high spot power prices.

Rotokawa (now 39 MW, 1997). This was another early IPP/RMA project, installed in two stages. It has a combined-cycle back pressure, binary condenser and binary brine plant, air cooled, which is very efficient overall. There is full reinjection including all condensate. The choice was influenced by getting the maximum MW for a defined quantity of fluid, concerns for back-end turbine wetness given the high resource temperatures (>300°C) and hence high separator and turbine inlet pressures, and as far as possible using existing wells drilled during earlier government exploration. The use of a combined cycle plant, with a back-pressure steam turbine exhausting to a binary plant, does have some definite advantages in avoiding steam turbine back-end erosion problems when using a saturated steam high inlet pressure. There have been very minor environmental effects. The second stage was similar to the first. The Nga Awa Purua plant on the same field is discussed separately below.

Ngawha (now 25 MW, 1998). This was another early IPP/RMA project. It is a pure binary plant, air cooled. There is full reinjection including all condensate, now plus about 5% extra water to maintain reservoir pressures, which is an unusual situation world-wide. The choice of plant was largely dictated by the low resource enthalpy and high gas content, and influenced by getting maximum MW for a defined quantity of fluid from existing wells, though there were not too many other practical technical alternatives. The small initial size of the project (10 MW compared to 40 MW applied for) was totally dictated by environmental concerns, especially possible effects on the thermal pools. In practice there have been very minor or no environmental effects. The second stage is similar to the first.

Mokai (now 100 MW, 1999). This was an early IPP/RMA project, very similar to Rotokawa and likewise installed in two stages plus some later re-configuration. It is a combined-cycle back pressure, binary condenser and binary brine plant, air cooled and like Rotokawa very efficient overall. There is full reinjection including all condensate. As at Mokai, the choice of plant was probably influenced by high resource temperatures, getting the maximum MW from a defined quantity of fluid, and from existing wells. The choice was possibly also influenced by the early involvement of Ormat who are said to have offered advantageous financial terms – the same efficiency could have been achieved using a multi-flash condensing turbine, but that would have taken much longer to procure and commission.

There have been very minor environmental effects. The second stage is similar to the first.

Wairakei/Tauhara later stages: Wairakei binary, Te Huka, Te Mihi (total 203 MW, from 2005). These comprise a bottoming binary plant, single and multi-flash condensing steam turbines. They have a mixture of air-cooled and (mostly) evaporative cooling towers. There is full reinjection apart from evaporation. The designs were in part driven by the need to minimize environmental impact, though part of the original Wairakei plant is still operating and discharging to the river, albeit with some efforts to reduce the quantity and to improve water quality. The design was presumably also influenced by the desire to get maximum MW from a defined quantity of fluid.

Kawerau (125 MW 2008). This is a double flash condensing single steam turbine with evaporative cooling towers and hence some fluid loss. There is full reinjection apart from evaporation. It incorporates acid injection to prevent silica deposition given the high resource temperature and low final flash pressure. The choice was presumably dictated by the need to extract maximum MW from a defined quantity of fluid, and to satisfy impacts within a multi-user resource.

Nga Awa Purua (140 MW, 2010). This is a separate project at Rotokawa, but with overlapping ownership with the other Rotokawa power plant. It has a triple flash condensing single steam turbine which at the time of writing is the largest in the world. It has evaporative cooling towers and hence some fluid loss. There is full reinjection apart from evaporation. It incorporates acid injection to prevent silica deposition. The choice was presumably dictated by the need to extract the maximum MW from a defined quantity of fluid.

Ngatamariki (80 MW, 2013). This plant has multiple pure binary units despite being located on a high temperature resource. It is air cooled with no condensate evaporation and full reinjection. The choice was dictated by environmental concerns, namely a desire to minimize any impact on reservoir pressures and thereby avoid subsidence, hydrothermal eruptions, and any effects on the nearby protected Orakei Korako thermal area. The proposal to do so was the developer's initiative, not apparently dictated by the regulatory authorities, and without any proven pressure connection between Ngatamariki and Orakei Korako. The decision is an interesting one, as it presumably represents a significant lost opportunity in terms of efficiency/MW-net generation, compared to a multi-stage condensing turbine or combined-cycle plant extracting the same amount of fluid.

SUMMARY & CONCLUSIONS

Despite both having long histories of large scale development of high temperature, volcanic-related geothermal resources, New Zealand and Indonesia have made use of rather different geothermal energy conversion technologies. Some but not all of those differences can be explained in terms of differences in resource characteristics. The differences are also related to the types of regulations and policies (resource access, electricity market; and environmental policy) that were in place in each.

The more flexible power market in New Zealand has led to a wider range of business models including multiple ownership on a single resource, and in some cases such as Poihipi it has directly affected the technology and plant size selection.

Two of the more significant regulatory differences are that in New Zealand resources are allocated as a fluid take (tonnes-per-day/annum as a consentable unit). Quantity and sustainable management of the resource, and its related thermal activity and ecosystems are guiding principles in New Zealand. On the other hand in Indonesia allocation is on the basis of MW, regardless of how much fluid extraction it takes to achieve that. This has led to the adoption in NZ of plant with the ability to extract more MW per tonne of fluid produced, albeit at higher capital cost per MW produced.

The fact that reinjection is mandatory in Indonesia but not in NZ has also been a significant factor in technology selection, with some older plants in NZ still discharging brine and condensate to waterways. At the same time, the perceived need to prevent undesirable environmental effects has led in the case of Ngawha and the most recent plant at Ngatamariki to the use of air-cooled pure binary plants to conserve condensate for injection and reservoir pressure support.

We conclude that regulation and market settings can enhance or inhibit innovative solutions in geothermal energy projects. In neither country are the adopted solutions always the most technically or economically efficient. There may be good policy (and business) reasons for the choices adopted but it is as well to make these explicit.

A new Geothermal Roadmap as well as implementation and pricing regulation as suggested by EBTKE in Indonesia seem to specifically aim at allowing more flexibility in geothermal technologies installed, which should in turn promote the faster roll-out of new geothermal installations including of retrofitted binary bottoming plants.

The same general principles and possible lessons will apply to other countries as well.

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