OHAAKI RESOURCE ASSESSMENT IN UNFC FRAMEWORK AND PROPOSAL

Bart van Campen[1], Rosalind Archer[1] and David Grinlinton[2]

[1] University of Auckland Geothermal Institute, 12 Grafton Rd, Auckland, New Zealand

[2] University of Auckland Law School, 12 Grafton Rd, Auckland, New Zealand

b.vancampen@auckland.ac.nz

Keywords: geothermal, resource assessment, Ohaaki, regulation, resource management, sustainability

ABSTRACT

Ohaaki resource assessments are reviewed over its long exploration and production history. The recently IGA-adopted UNFC resource classification framework and geothermal specifications are used to categorize these resource assessments and analyse changes over time, in the context of changes to NZ regulate ons and electricity market.

With the lessons from such a review, a proposal is presented to use the same UNFC based method to classify all NZ/Waikato geothermal systems as a basis of future resource management. Historic data is used to illustrate this and a proposal is presented how to gather data for an update.

1. INTRODUCTION

It is clear Ohaaki has gone through a long exploration and production history and a range of resource assessments, as well as actual production stages (e.g. see van Campen-Archer, 2017, and summarized in annex-1).

In this article, we'll use the recently accepted UNECE-IGA Geothermal Specifications (2016) to the UNFC resource classification system as a common basis to classify these historic assessments. Of course at the time, the original assessments were not actually created with the UNFC system in mind; hence such ex-post use might seem inappropriate. On the other hand, the UNFC system doesn't actually prescribe any assessment quantification methods, but merely gives guidance how to classify such assessments with transparent specification of methods and assumptions used. The UNFC system (UNECE, 2013) classifies according to 3 axes:

- E-axis: Economic and social viability (1-3)
- F-axis: Field project status and Feasibility (1-4)
- G-axis: Geological knowledge/level of confidence in recoverability (1-4)

This makes the 3-dimensional UNFC system slightly more complicated than comparative 2-dimensional systems like SPE-PRMS (2011) for petroleum resources or CRIRSCO for mineral resources (which forms the basis for the AGEA Geothermal Code (2010). However, as the E- and F-axis are correlated, 5 Primary resource reporting Classes remain, over the 3 main economic dimensions, which can be represented in two dimensions (see figure 1 below):

1) Commercial Projects (E1F1), marked in green, and comparable to PRMS-class of 'reserves'

2) Potentially Commercial Projects (E2F2), marked in yellow-orange;

3) The E3-category in UNFC is somewhat more complicated as it includes non-commercial projects (G3F2-red), and Exploration projects (E3F3G4-blue), as well as 'additional quantities in place' (E3F4-grey), before drilling has taken place;

	Class	Categories		
		E	F	G
Future recovery by commercial development projects	Commercial Projects	1	1	1, 2, 3
Potential future recovery by contingent development projects	Potentially Commercial Projects	2	2	1, 2, 3
	Non-Commercial Projects	3	2	1, 2, 3
Additional quantities in place associated with known energy sources		3	4	1, 2, 3
Potential future recovery by successful exploration activities	Exploration Projects	3	3	4
Additional quantities in place associated with potential energy sources		3	4	4

Figure 1: Two-dimensional view of UNFC Primary Classes (source: Ussher et al 2018; UNECE-2013, p 5)

In the context of New Zealand exploration history and regulation, this last category is particularly confusing, as most TVZ geothermal systems have/had been explored and drilled by the government in the 1960s-1980s (i.e. 'known' or discovered deposits/systems), without a necessarily strong relation to the economic viability (E-axis). On the regulatory side, New Zealand has a rather unique regulatory system (e.g. Lawless et al, 2016 discussing the Resource Management Act, RMA-1991), where resource consent and access is not allocated through a national authority on the basis of ownership and economic resource management. Instead consent is granted through regional authorities on the basis of 'sustainable resource management' for future generations, while land/resource access has to directly negotiated with the landowner. Sustainable management here means some systems/resources have been allowed to be gradually depleted over time (multiple generation, ~ 50-100 years), while other systems are protected. To justify and monitor the resource allocation, regional authorities like Waikato Regional Council have seen fit to create an overall assessment of their 'sustainable geothermal resource'. As this 'sustainable geothermal resource' doesn't require a direct relation to project Economics or Feasibility, it would seem closest to the UNFC' E3-F4 category of 'additional quantities in place'. The suggestion is to bundle these into 1 category E3-Grey for the purposes of this classification exercise.

Applying this to the various Ohaaki resource assessments results in the overview in Annex 1. Below the Ohaaki resource assessments and changes in UNFC-categorization at 6 of the most important historic moments (and an attempt at future assessment) will be discussed in more detail:

1) MWD (1971): final assessment on closing Ohaaki exploration;

2) 1978 Environmental Impact Audit (CfE, 1978) and Water Rights allocation (based on Broadland Investigation Report MWD, 1977)

3) 1988/89 Commissioning of Ohaaki Power Plant

4) 1998 Re-consent (Contact, 1998)

5) 2002 Waikato Regional Council (WRC) Resource Assessment of all Waikato High Enthalpy Resources (WRC/SKM, 2002)

6) 2013 Re-consent (Contact, 2013)

7) Future assessment

2. OHAAKI UNFC CASE STUDY

Project Summary:

Project Location: Ohaaki, Broadlands, Waikato, New Zealand

Date of Evaluation: September, 2019

Product Type: electricity

Reference Point for all projects is the station switchyard, where the power is exported to the grid. Hence, all quantities refer to net power generation (unless otherwise specified).

Summary Ohaaki Project

There are considered to be two upflows of high enthalpy fluids in the Ohaaki system, the main recharge coming from a confined area on the West Bank, with a small contribution from the East Bank. These separate upflows have been inferred from the differing chemical signatures of the fluids from each production area. Deep drilling has not discovered significant permeability in the greywacke which underlies the East Bank (It is likely that part of the West Bank recharge migrates to the East Bank along a zone of enhanced permeability close to, or along the greywacke interface). The Ohaaki Power Station is powered from these 2 separate production areas. On both the East and the West Bank, a small portion (~20%) of the intermediate pressure steam comes from wells drilled into the intermediate aquifer (400 – 1200 m depth). However, since 2007 all the high pressure steam and the majority (~60%) of the intermediate pressure steam comes from wells drilled into the deep reservoir (>1200 m).

Ohaaki government-led exploration started in the 1960s, and the plant was consented for 20 year production in 1978. However, the plant was only commissioned in 1989, by which time 49 wells had been drilled. In 1996 Ohaaki became part of the SOE Contact Energy group (to be privatized and listed on the NZX in 1999). The power station was re-consented for lower production levels in 1998 (15 years) and again in 2013 (for 35 years).

2.1 MWD (1971) final assessment at close of Ohaaki exploration

Geothermal Energy Resources Classification:

100-180MWe* ? years (E3.3; F2.3)

Best estimate: 76 PJ (G1+G2)

High estimate: 136 PJ (G1+G2+G3)

Data date: 1971

Quantification methods: well power extrapolation and well decline analysis

Estimate type: deterministic

Discussion: note that the 1971 assessment actually doesn't define how many years the 100-180 MWe project would be expected to run for, but 30 years was usual at the time for project horizon. This was used for the energy (PJ) calculations. It was also unclear whether is was nett or gross electricity. Nett is assumed. A conservative CF of 80% was used.

Category	UNFC definition	Reasoning for classification
E3	*Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability*	At the time of assessment, the government reasoned that the availability of plenty of economic hydro and gas-fired generation made new geothermal generation and Ohaaki unattractive and all further exploration and development was halted.
Subcategory	**UNFC definition**	
E3.3	*On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.*	
Category	**UNFC definition**	**Reasoning for classification**
F4	*No development project or mining operation has been identified.*	18 wells drilled and extensively flow tested. Reinjection necessary and performed in other countries, but not yet on 2-phase systems and such large quantities of fluid.
Subcategory	**UNFC definition**	
F4.1	*The technology necessary to recover some or all of the these quantities is currently under active development, following successful pilot studies on other deposits, but has yet to be demonstrated to be technically feasible for the style and nature of deposit in which that commodity or product type is located;*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	18 wells drilled and extensively flow tested, but significant uncertainties around permeability, well decline, cold water inflow, etc affecting long-term production estimates
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.2 1978 Environmental Impact Audit and Water Rights allocation (based on Broadland Investigation Report)

Geothermal Energy Resources Classification: 80MWe*20 yrs (E2; F2.1; G1+G2)

Best estimate: 43 PJ (G1+G2: 80 MWe * 20 yrs)

High estimate: 48 PJ (G1+G2+G3: 90 MWe * 20 yrs)

Data date: 1977-1978

Quantification methods: lumped parameter model, volumetric assessment and well decline analysis

Estimate type: deterministic

Summary project changes: Between exploration closure in 1971 and the consent hearings in 1978, the oil shocks of the 1970s and the 1970-report by the Club of Rome 'The Limits to Growth', the government became interested again in exploring non-fossil, indigenous, non-hydro energy resources. This was reinforced by 2 droughts in 1973 and 1974. Exploration was restarted and 15 more wells drilled. A preliminary project design and costing was done, and application for environmental consent and Water Rights was made and ultimately approved. The plant was to be built and commissioned by 1982.

Discussion: The original plan and application were for a 150 MWe (nett) project and accompanying water rights (103,200 tpd of fluid take) for a period of 20 years. During the environmental hearing uncertainties were discussed, and late in the process the central government body responsible for generating electricity at the time, the New Zealand Electricity Department (NZED) submitted that the development would be in 2 phases: phase-1 of 80-90 MWe-Nett, while phase 2 would further develop the plant to the planned 150 MWe-Nett 'after several years of proven operation'. The Water Rights and environmental consent were granted in 1978 for the full, original application of 103,200 tpd (150 MWe * 20 yrs – E3; 2.2 ; G1+G2).

Category	UNFC definition	Reasoning for classification
E2	*Extraction and sale is expected to become economically viable in the foreseeable future.*	Water Rights and Environmental Consent awarded, preliminary costing done and expected to be economically feasible
Category	**UNFC definition**	**Reasoning for classification**
F2	*Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.*	Preliminary design approved. Detailed design to follow. Challenging design and other issues (land rights) expected.
Subcategory	**UNFC definition**	
F2.1	*Project activities are ongoing to justify development in the foreseeable future.*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	*33 wells drilled and extensively tested. Moderate confidence that 1st phase of project would support 80 MWe-Nett*
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.3 1988/89 Commissioning of Ohaaki Power Plant

Geothermal Energy Resources Classification: 108 MWe * 10 yrs (E1 ; F1.1 ; G1+G2)

Best estimate: 31 PJ (G1+G2: 108 MWe * 10 yrs)

Data date: 1988

Quantification methods: well decline analysis and plant design (reservoir model being tested)

Estimate type: deterministic

Summary project changes: After the granting of environmental consent and Water Rights in 1978, detailed design and project preparation were given the green light. Technical design issues and land access/ownership negotiations caused considerable postponement. In 1983-1984 the design was changed to include 2 excess HP-turbines from Wairakei, which were estimated to use Ohaaki excess high pressure steam for around 10 years. By the time the Ohaaki plant was commissioned in 1988/89 10 years of its original Water Rights had already elapsed.

From the 1980s onwards the University of Auckland developed reservoir models for Ohaaki, but these played no role in the build decisions.

Discussion: The original project was modelled for 30 years production. Hence, after the remaining 10 years on the original Water Rights were to be finished, potentially an additional 80 MWe could be available for another period of 20 years, depending on consenting, additional drilling and economic circumstances. Under UNFC this would be seen as a separate project: 80 MWe * 20 yrs (E3 ; F2.2 ; G1+G2)

Category	UNFC definition	Reasoning for classification
E1	*Extraction and sale has been confirmed to be economically viable*	Plant built and commissioned with 2 * 48 MWe IP and 2* 11 MWe HP turbines (116MWe-gorss; 108 MWe-nett). HP turbines were expected to run 10 yrs on excess high pressure steam, then mothballed. At the time only 10 yrs were remaining on the original Water Rights
Subcategory	**UNFC definition**	
E1.1	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions*	
Category	**UNFC definition**	**Reasoning for classification**
F1	*Feasibility of extraction by a defined development project or mining operation has been confirmed.*	Extraction and generation is taking place. Reinjection protocols still to be tested, but confident for first 10 years.
Subcategory	**UNFC definition**	
F1.1	*Extraction is currently taking place.*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	*Confident that excess geothermal steam for additional HP-turbines would last 10 years with planned make-up drilling.*
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.4 1998 Re-consent

Geothermal Energy Resources Classification: 70 MWe * 15 yrs (E1 ; F1.1 ; G1+G2)

Best estimate: 30 PJ (G1+G2: 70 MWe * 15 yrs)

High estimate: 34 PJ (G1+G2+G3: 80 MWe * 15 yrs)

Data date: 1997

Quantification methods: reservoir model

Estimate type: deterministic

Summary project changes: After the commissioning in 1988/89, the Ohaaki power plant ran at full capacity for around 5 years (1993/4) after which steam pressures (esp HP) and volumes started to drop. Of the 3 make-up wells per year predicted/planned only 3 were drilled between 1989 and 1998. In 1991 the new Resource Management Act (RMA) was introduced, and Ohaaki was one of the first geothermal plants to be re-consented under the RMA. In 1996 electricity market liberalization culminated in the start of New Zealand Electricity Market (NZEM)-trading and the split-off/sale of Contact Energy as a private generator, including ownership of Ohaaki. Power prices were expected to drop in the years to come.

Discussion: The original consent application was for 30 years, but due to uncertainties (esp subsidence) the consent was only granted for 15 years. Additional generation was demonstrated to be feasible beyond 2013-2035 according to the model, although with declining pressures: 60 MWe * 23 yrs (E3 ; F2 ; G1+G2 = non-commercial project). This would be categorized as a separate project under UNFC.

Category	UNFC definition	Reasoning for classification
E1	*Extraction and sale has been confirmed to be economically viable*	Power prices dropping but Ohaaki deemed economic on smaller operation. Scenarios based on Tough2 reservoir model with 10 years worth of production data, moderate fit and a 'robust' scenario of 6 make-up wells, run until 2035 (38 yrs). But uncertainties and declining production after 2013.
Subcategory	**UNFC definition**	
E1.1	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions*	
Category	**UNFC definition**	**Reasoning for classification**
F1	*Feasibility of extraction by a defined development project or mining operation has been confirmed.*	10 years of production/operation, but main uncertainty in management of subsidence/surface effects. Consent awarded for 15 years until 2013 due to uncertainties.
Subcategory	**UNFC definition**	
F1.1	*Extraction is currently taking place.*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	Confident that new wells drilled in deeper East Bank would be good producers.
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.5 2002 WRC Resource Assessment of Waikato High Enthalpy Resources

Geothermal Energy Resources Classification: 120 MWe * 30 yrs (E3.3 ; F4.2 ; G1+G2)

Best estimate: 102 PJ (130 MWe-gross; 120 MWe-nett * 30 yrs)

Data date: 2001

Quantification methods: volumetric assessment

Estimate type: probabilistic

Summary project changes: The 2002 Resource assessment was not so much warranted by project changes or consenting requirements, but the result of the desire by the regulator, Waikato Regional Council (WRC), to create an assessment of all (high enthalpy) geothermal resources in the region: those classed as 'development', as well as 'protected' and other regulatory classifications. This would be the basis for WRC regional geothermal resource management policy, which requires 'sustainable resource management'. As most geothermal fields in NZ had been thoroughly explored by the government in the 1960s-1980s, public data is/was available for most fields. The Ohaaki field was also assessed, using the same probabilistic volumetric resource assessment.

Discussion: The WRC volumetric assessment for Ohaaki was considerably higher than the 40 MWe Ohaaki operations at the time (or even the 80 MWe consented). The assessment used public data only, and ignored existing production history, and was actually treated as 'pre-development conditions'. It is important to recognize that the WRC assessment(s) was (were) not directly related to project economics or feasibility, but regulatory requirements. A P10 estimate of 100 MWe (gross; around 90 MWe nett) was also produced in the same assessment.

Category	UNFC definition	Reasoning for classification
E3	*Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability*	Present smaller Ohaaki project running, but more 'sustainable' resource might be available, without being economic at the moment
Subcategory	**UNFC definition**	
E3.3	*On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.*	
Category	**UNFC definition**	**Reasoning for classification**
F4	*No development project or mining operation has been identified.*	Significant additional heat demonstrated in deep basin, but low permeability. Would need 'enhancements'
Subcategory	**UNFC definition**	
F4.2	The technology necessary to recover some or all of these quantities is currently being researched, but no successful pilot studies have yet been completed	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	P50 volumetric estimate
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.6 2013 Re-consent

Geothermal Energy Resources Classification: 55 MWe * 35 yrs (E1 ; F1.1 ; G1+G2)

Best estimate: 55 PJ (G1+G2: 55 MWe * 35 yrs)

High estimate: 60 PJ (G1+G2+G3: 60 MWe * 35 yrs)

Data date: 2012

Quantification methods: reservoir model

Estimate type: deterministic

Summary project changes: After NZEM power prices dropped from 1996 to the early 2000s, two droughts in 2001 and 2003, and the foreseeable end of the cheap Maui gas contract, started pushing up power prices and average wholesale prices almost doubled over the 2000s. In 2008 New Zealand introduced a comprehensive Emissions Trading Scheme, putting downwards pressure on coal and gas-fired generation. Many new power projects were investigated, consented and developed (especially geothermal and wind). Between 2008-2010, 12 new wells were drilled in Ohaaki's deep West Bank reservoir and generation rose back to 70 MWe (nett). However, in the early 2010s electricity demand growth stagnated, and oversupply resulted. Ohaaki generation was allowed to drop to 45-50 MWe (nett) by the time of re-consenting in 2013.

Discussion: The consent application discusses the option of deriving an additional ~20 MWe generation with same fluid extraction if the second/spare IP-turbine were to be converted to an LP-turbine to make use of remaining pressure and energy after the running IP-turbine. This extension project would be dependent on resolving economic and technical challenges: 20 MWe*35 yrs (E2 ; F2.1 ; G1+G2). Additional generation beyond the consent limit of 2048 was demonstrated to be feasible according to the reservoir model running until 2060: 55 MWe * 12 yrs (E3 ; F2 ; G1+G2). The latter would be seen as a separate, non-commercial project under UNFC.

Category	**UNFC definition**	**Reasoning for classification**
E1	*Extraction and sale has been confirmed to be economically viable*	Resource proven with a well-calibrated Tough2 reservoir model (25 yrs of production history; good match) and a range of scenarios. Chosen and consented scenario with 16 wells (within 20 wells criterium).
Subcategory	**UNFC definition**	
E1.1	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions*	
Category	**UNFC definition**	**Reasoning for classification**
F1	*Feasibility of extraction by a defined development project or mining operation has been confirmed.*	Successful operation has been on-going for 25 years, and confident for future operation.
Subcategory	**UNFC definition**	
F1.1	*Extraction is currently taking place.*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	*Confident that additional heat resource is available in the reservoir.*
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

2.7 Future assessment

Geothermal Energy Resources Classification: 45 MWe * 30 yrs (E1 ; F1.1 ; G1+G2)

Best estimate: 38 PJ (G1+G2: 45 MWe * 30 yrs)

Data date: 2019

Quantification methods: extrapolation of existing production and System Management Plans

Estimate type: deterministic

Summary project changes: With the above historical assessments in mind and insight in recent production, Annual Reports and System Management Plans, a 'mock' Ohaaki resource assessment for the coming 30 years can be done. Since 2013 electricity demand has started to grow again and market prices are rising. However, emission prices have also been rising and Contact Energy has the large, consented Tauhara-II project ready to invest. Ohaaki geothermal field has a high CO_2-content and didn't qualify for Contact's certified 'green energy' bond (CBI-standard<100 g CO_2/kWh). Production has been allowed to drop to ~45 MWe and the plan is to maintain at this level with a new well every 3 years (vs 1 per 2 years as planned in 2013 re-consent).

Category	**UNFC definition**	**Reasoning for classification**
E1	*Extraction and sale has been confirmed to be economically viable*	In the present economic circumstances, Contact Energy has invested less in make-up wells than planned and is aiming to maintain production around 45 MWe
Subcategory	**UNFC definition**	
E1.1	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions*	
Category	**UNFC definition**	**Reasoning for classification**
F1	*Feasibility of extraction by a defined development project or mining operation has been confirmed.*	Successful operation has been on-going for 25 years, and confident for future operation.
Subcategory	**UNFC definition**	
F1.1	*Extraction is currently taking place.*	
Category	**UNFC definition**	**Reasoning for classification**
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	*Confident that additional heat resource is available in the reservoir.*
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence*	

Discussion: In principle the same, consented amount of fluid and generation is still available (though deemed less economic under present market conditions), including the additional ~20 MWe generation from the IP-LP-turbine conversion. Dependent on resolving economic and technical challenges. This would be seen as a separate project/decision. Total (cumulative) potentially commercial project: 75 MWe*30 yrs (E2 ; F2.1 ; G1+G2).

3. CONCLUSIONS AND PROPOSAL

The above review shows how the UNFC classification system can help organize and categorize resource assessments for a better understanding of geothermal potential and development over time. Some observations regarding application of UNFC in the New Zealand context:

1) In general, the UNFC system is more extensive and complicated than SPE-PRMS (petroleum) or the existing AGEA Geothermal Code (2010, now abandoned), and can be somewhat confusing, especially when categorizing earlier exploration stages and upside to existing projects;

2) The UNFC classification system is a project based system, but can be used as a basis for regional or national resource reporting and aggregation. The UNFC geothermal specifications recognize that resource assessments by/for (commercial) developers, might be different from those done for/by regulators.

3) Under the present NZ geothermal RMA-regulation, developers only need to demonstrate resource availability at the moment of applying for a resource (production) consent. As the RMA-regulation requires councils to apply a ‘precautionary principle’, successful resource applications will generally be conservative and ‘well-proven’ with reservoir models and other data sources. Such resource assessments can therefore be seen as ‘high confidence’: E1 F1 G1. Such resource consents and reservoir modelling reports are generally publicly available, so estimates of commercial (running, producing) projects are relatively easy to do in NZ;

4) On the other hand, the RMA (1991) geothermal regulation is water-based; hence consents are mostly defined in terms of mass of fluid extracted/reinjected. The exact MWe produced are less of a concern for the regulating authorities (regional councils), and reporting/updates are often less clearly defined in max/planned production, nett/gross, etc and vary per system (developer/peer review panel). As this type of (consistent) information is important at an energy planning (national) level (and becoming more so in the context of increased policy ambitions for reduced national GHG emissions – see 3.2), the recommendation would be to require regular (e.g. every 5 years) updates of geothermal generation potential, using a common, well-defined standard (esp using UNFC system; well-discussed and coordinated with regional and national authorities, as well as developers). This could well be done in line with the required 5-yearly reservoir model update and System Management Plan;

5) For non-producing (potentially commercial) geothermal projects there is no reporting requirements under the RMA. Most NZ geothermal systems have been explored and drilled by the government in the 1960-1980s, so for most fields preliminary exploration data, such as geochemical, temperature and resistivity profiles are available, which can be the basis for high-level assessments (e.g. WRC-2002 volumetric stored heat assessment). In recent years, exploration has been by commercial developers only and data is kept confidential. Government-led exploration by central government science agencies DSIR/GNS has been abandoned in the geothermal sector; there is no similar role as in the petroleum sector or US Geological Survey. This has left a gap in data gathering for national (and regional) geothermal resource assessment that can only be filled by parties working together.

6) The same inconsistency in data reporting between different fields/developers and regional vs national authorities became clear from analysing geothermal primary energy data from regional and national sources; as well as CO_2/CH_4 emissions data. Publication has been delayed due to data confidentiality issues.

7) Because of the split responsibilities between national and regional authorities in New Zealand in managing geothermal energy resources, no recent assessment of NZ geothermal resources has been done. The example method and lessons learnt could be applied to update the NZ/Waikato geothermal resource assessment (last time in 2002).

3.2 Proposal for updated geothermal resource assessment (in NZ/Waikato), using UNFC

Using the classification method based on UNFC, and the lessons from the Ohaaki case study, a similar approach could be taken to classify the New Zealand/Waikato geothermal resources. The last time this was done, was in 2002. Much has changed in terms of geothermal exploration and development, as well as market and policy settings. The new, central government aim to reach 100% renewables in the electricity sector by 2030, and further evolution to carbon neutrality in 2050, will require considerable expansion of New Zealand geothermal generation and direct (industrial) heat use. An important question is how/whether that amount of geothermal resources can be developed, while maintaining a focus on ‘sustainable resource management’.

The following steps are proposed to update NZ’s geothermal resource overview:

1) Discuss (with WRC and Ministry of Business, Innovation and Employment (MBIE)) that UNFC is a classification system only, with no definitions (yet) on quantification methods and defaults. One could refer to among others the Lexicon to the Australian Code (2011) with variations where necessary:

- Reservoir modelling is the preferred, most accurate method, but:

- Volumetric assessment is the only method that is consistently applicable across all geothermal development stages and resource categories.

2) Discuss and agree how WRC sees its 'sustainable resources' on the UNFC categories; (proposal is as E3F4G3 ‘additional quantities in place’). A re-casting of the 2002-WRC resource study on the UNFC scale would be simple and probably illustrative to come to an agreement of method and classification. The recommendation would be to use 3 the UNFC-categories as applied in the Ohaaki case:

a. Total, sustainable resource available (WRC-definition). As this would not include expectation of this resource being developed/economical in the foreseeable future (actually some resources are protected), this would probably be in the E3 -F2/4 - G2/3 category (to be defined). Once well-defined and agreement on method, that should doable;

b. Then there are the running/consented commercial projects (E1F1G1); those are easy to identify and the consent/resource assessments should be available to quantify these; as well as the consent timeframes still left (mostly 25+ years as most have recently been (re)consented). These resource quantifications should be considerably smaller, illustrating the (present) gap between resources available and feasible/economic development (in the foreseeable future), but should also show which resources are still available

This is also the resource category you'd expect developers to report on when applying for (re)consent and in their 5-yearly SMPs.

c. Then there is the intermediate category of 'potentially commercial projects', upsides to existing projects, etc (E2, F2, G2-3). For many in the sector/market this would be the interesting category of what additional resource capacity might be available in the next 5-10 years to expand geothermal. As mentioned, in the New Zealand regulatory context, developers are not required to report any resource at this stage. It is expected information will therefore be difficult to gather, and a combination of volumetric assessment (with more conservative values), and market/key person information might be necessary;

3) Then for doing the re-assessment itself, several sources and methods should be used:

a) For all systems a re-run of the 2002 probabilistic volumetric assessment, with new/re-interpreted geological, technical (and constraints) data; e.g. the recovery factor for the Ohaaki system would have to be lowered/penalised from

the one used in the 2002-study to account for subsidence and other constraints;

b) For the producing systems and those with Annual Reports/SMPs and recent Reservoir Modelling/consent reports available, base assessments on these reports;

c) Other/key informant information on explored, not-protected, but non-producing systems like Tokaanu, Reporoa, Mangakino, Tikitere.

d) For protected systems 2a) is likely to be the only method available.

Together the above mix of methods should provide a nuanced picture of 'sustainable' resources and developable - (potentially) commercial projects.

If a preliminary assessment is based on the above method, but using existing information, an overview like the one in Annex-2 will result. This shows that a considerable amount of additional geothermal capacity is available in New Zealand, beyond the presently producing/consented systems, but not as much as has previously been quoted, as many of these systems are protected or only for 'limited development'. The overview also illustrates that the main information problem is in the 'potentially commercial projects' (the next cab off the rank), which is in large part due to the lack of reporting requirements for non-consented geothermal projects in New Zealand. It will require cooperation between national and regional authorities, as well as developers and land-owners/iwi in New Zealand to improve this information gathering situation and improve the resource assessments.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the assistance and permission of Contact Energy, especially Warren Mannington, to carry out and publish this research.

REFERENCES

AGEA (2010); The Geothermal Reporting Code; Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves; 2nd edition, 2010;

AGEA (2011); Geothermal Lexicon for Resources and Reserves Definition and Reporting; 2011;

CfE (1978): Commission for the Environment. Broadlands geothermal power development – environmental impact audit; Wellington, 1978

Contact (1995): Ohaaki geothermal field - 1995 annual report on monitoring and reservoir performance. Contact Energy Geothermal, 1995.

Contact (1998): Ohaaki geothermal field management plan. Contact Energy Limited, 1998.

Contact. (2013): Ohaaki draft system management plan - appendix A-part C of 2013 consent application. Contact Energy Limited, April 2013.

Contact-ARS. (1996). Contact annual report to shareholders, 1995/1996 Contact Energy.

Contact-SKM. (2013). Ohaaki geothermal power plant project description -part B appendix A of 2013 consent application. Contact Energy Limited, April 2013.

Donaldson, I. G., & Grant, M. A. (1978). An estimate of the resource potential of New Zealand geothermal fields for power generation. Geothermics, 7(2), 243-252. doi:10.1016/0375-6505(78)90014-7.

Freeston, D. H., & Thain, I. A.1990-1995 update report on the existing and planned of geothermal energy for electricity generation and heat use in New Zealand. Paper presented at the World Geothermal Congress 1995.

Kortright, N. I. Impact of the resource management act on future geothermal development in New Zealand. Paper presented at the World Geothermal Congress 2015; 21(5) 1-11.

Lawless at al (2016); John Burnell, Bart van Campen, Noel Kortright, Jim Lawless, Jim McLeod, Katherine Luketina, Bridget Robson: Sustainability of TVZ Geothermal Systems: the Regulatory Perspective ; Geothermics 59 - TVZ Special Issue; January 2016.

MWD (1977): Broadlands Geothermal Investigation Reports. Ministry of Works and Development, Wellington, 1977.

NZED (1977): Environmental impact report for the Broadlands geothermal power development. New Zealand Electricity Department, Nov 1977.

O'Sullivan, M., & et al. (2015; Mike O'Sullivan, Emily Clearwater, Angus Yeh, John O'Sullivan, Aneesh Shinde, Sadiq Zarrouk, Juliet Newson and Warren Mannington: Computer modelling retrospective on Wairakei and Ohaaki. Paper presented at the World Geothermal Congress 2015.

SPE-PRMS (2011): Guidelines for Application of the Petroleum Resources Management System; Society of Petroleum Engineers; November 2011.

Thain, I. A., and Dunstall, M: 1995-2000 update report on the existing and planned use of geothermal energy for electricity generation and direct use in New Zealand. Paper presented at the World Geothermal Congress 2000, 1-9.

UNECE (2013): United Nations framework classification for fossil energy and mineral reserves and resources 2009 incorporating specifications for its application. United Nations Economic Commission for Europe, ECE ENERGY SERIES No. 42.

UNECE. (2017): Application of the United Nations framework classification for resources (UNFC) to geothermal energy resources - selected case studies. United Nations Economic Commission for Europe, ECE ENERGY SERIES No. 51.

UNECE-IGA. (2016): Specifications for the application of the United Nations framework classification for fossil energy and mineral reserves and resources 2009 (UNFC-2009) to geothermal energy resources. United Nations Economic Commission for Europe, International Geothermal Association, Geneva, September, 2016.

Van Campen-Archer (2017): Ohaaki consenting, modelling and resource assessment review: the best place to look for lessons on sustainable geothermal operation and monitoring; NZGW 2017.

WRC/SKM (2002): Resource capacity Estimates for High-Temperature Geothermal Systems in the Waikato Region. Report for Waikato Regional Council, 2002.

Annex 1: Resource Assessment Ohaaki over time with UNFC

		Sustainable Regional Resource Overview: Cumulative Quantities (Historically) in Place or Remaining (no regard for consenting or economics)		Project with Development Potential (for which commercial interest has been shown); generally little public data available		Consented projects: operational or committed	
		Potential Deposit		**Known Deposit**			
	UNFC Classes	**E3 - F4- G1-3/4 - Additional quantities in place (cumulative)**		**E2-E3/F2 - potentially commercial projects and non-Commercial projects (?upside to existing commercial projects)**		**E1/F1/G1: Commercial and Consented Projects**	
		Regulator's (WRC) 'Sustainable Resource' from 30 Yr-Capacity median/best estimate based on WRC/SKM & NZGA (2001/2) Volumetric Heat Assessments		**E2: Potentially Commerical in the 'foreseeable future' (max 5 yrs)**		**E1: Extraction taking place or 'within reasonable timeframe'**	
	1964/5	E3F3G4 - Exploration Results	< 200 Mwe				
		After drilling					
	1968				90 Mwe (gross) * ? Yrs		
1	**1971 - Min Works assessment**			**E3.3 F2.3 G1+G2**	**76 PJ (100 Mwe (gross?) * 30 Yrs)**		
				G1+G2+G3	136 PJ (180 Mwe * ? Yrs; unclear whether gross or nett)		
	1977 Broadland Investigation Report and				100 Mwe (gross?) * 30 yrs; upto '150-160 Mwe * 50 yrs		
2	**1978 EIA & Water Rights**		Stage 2 (upto 150 Mwe*20 years) after field 'proven' after several years of operation. Separate project.	**E2 F2.1 G1+G2**	**43 PJ (80 MWe * 20 yrs)**		
				G1+G2+G3	48 PJ (90 MWe * 20 yrs)		
	Donaldson& Grant (1978)				Proven: 120 + 30 Mwe inferred * ? Yrs		
	1984-BuildDecision				80 Mwe * 14 Yrs + 20 Mwe HP * 10 Yrs		
3	**1988/89 Build and Commissioning**					**E1 F1.1 G1+G2**	**31 PJ (108 MWe * 10 yrs)**
	1989-1997 Operation						92 Mwe (Nett) * 9 Yrs
4	**1997/8 Re-consent**					**E1 F1.1 G1+G2**	**30 PJ (70Mwe * 15 Yrs)**
						G1+G2+G3	34 PJ (80 MWe * 15 yrs)
	1998-2012 Operation						46 Mwe (Nett) * 15 Yrs
5	**2001/2 WRC Resource Assessment**	**E3.3 F4.2 G1+G2**	**102 PJ (120 Mwe*30 yrs)**				
6	**2013-Re-consent**					**E1 F1.1 G1+G2**	**55 PJ (55 Mwe * 35 Yrs)**
						G1+G2+G3	60 PJ (60 MWe * 35 yrs)
	2013-2018 Operation						40 Mwe (Nett) * 6 Yrs
7	**Assessment 2019**					**E1F1G1**	***38 PJ(45 MWe * 30 Yrs)***

Annex 2 Preliminary resource assessment of NZ geothermal resources according to UNFC/proposed method

UNFC Classes	Potential Deposits	Known Deposits		
	E3 - F3/F4: Exploration Projects/Additional quantities in place	**E2-E3/F2- potentially commercial projects and non-commercial projects**		**E1/F1/G1: Commercial and Consented Projects**
NZ Interpretation	Regulator's 'Sustainable Resources'	Contigent Developments (next cab off the ranks)		Commercial Projects
Development Systems				
2 Horohoro (WRC)	5			0
4 Mangakino (WRC)	47			0
5 Mokai (WRC)	140			110
6 Ngatamariki (WRC)	120			80
7 Ohaaki (WRC)	130			45
10 Rotokawa (WRC)	300			170
11 Wairakei-Tauhara (WRC)	830			380
Ngawha (Northland RC)	75			25
Kawerau (BOPRC)	450			145
Rotoma (BOPRC)	35			0
Totals for Development Systems	**2,132**			**955**
Limited Development Systems				
13 Tokaanu-Waihi-Hipaua (WRC)	200			0
1 Atiamuri (WRC)	6			0
Rotorua (BOPRC)	35			0
Tikitere-Taheke-Ruahine (BOPRC)	240			0
Research Systems				
9 Reporoa (WRC)	42			0
Protected Systems				
3 Horomatangi (WRC)	380			0
12 Te Kopia (WRC)	96			0
14 Tongariro (ketetahi) (WRC)	100		0	0
8 Orakei-Korako (WRC)	110		0	0
15 Waimangu (WRC)	280		0	0
16 Waiotapu-Waikite (WRC)	340		0	0
Ketetahi (BOPRC)	100		0	0
Totals All Systems	**4,061**		**0**	**955**

CHALLENGE: PRESENTLY UNDER INVESTIGATION