Geothermal Resource Management and Reporting: learning from (NZ) petroleum regulator experience

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ABSTRACT

Geothermal energy is a clean and sustainable energy resource. In many countries with naturally occurring hydrothermal resources (like Iceland, Italy, New Zealand and the Pacific Rim of Fire) geothermal power plants have been successfully generating for more than 60 years. However, even in countries with long production histories and strong sustainability regulation (like New Zealand and Iceland), monitoring (and therefore ultimately managing) this sustainability has been hampered by the lack of international, harmonized reporting standards (e.g. see Lawless et al., 2016; IGA, 2015).

New Zealand has set itself the aim to meet 90% of its electricity production from renewable resources by 2025 (presently at ca 80%) and geothermal is a large part of that vision. It also has a long history of geothermal generation, sustainability regulation and monitoring, which also have been hampered by lack of harmonized reporting (e.g. see Lawless et al, 2016). The main regulator (Waikato Regional Council) has recently started consulting with the sector for its 2017 policy review about using more standardized reporting methods, e.g. a modified version of the Australian/Canadian Code (Maunder, 2014) or the new proposed UNECE-UNFC-2009.

In the meantime, after years of consultation from 2008 to 2012, NZ Petroleum & Minerals (Crown Minerals Act, 2013) has changed its petroleum regulation (no capitals needed) regime in 2013 from a relatively 'liberal' (had I already mentioned that I was not so comfortable with the use of "laissez faire") model, to a more prescriptive 'North Sea'-type model, among others prescribing the SPE-PRMS (2011) standards for reserve reporting (e.g. as used in The Netherlands, UK and Norway). Data reporting (quantity and quality) and management of NZ petroleum resource as a whole, has been greatly enhanced over the last 2 years.

This article compares regulation, reporting and aggregation/management practices in NZ for geothermal & petroleum and tries to derive some lessons.

1. INTRODUCTION

New Zealand has set itself an (aspirational) goal of meeting 90% of its electricity production from renewable resources by 2025 Presently this stands at about 80%, but in 2015 several of the remaining baseload gas and coal-fired plants were announced to be closed and many renewable (wind and geothermal) power projects are ready to be implemented. There are also plans to use more geothermal resources for direct heat use. Most of the (detailed) information about NZ's geothermal resource/reserve potential is with the developers and (partially) with the regional councils that regulate the resource. These regional councils (these what?) do not play a role in energy planning. The last 'national' geothermal resource overviews were made in 2001/2 as probabilistic, volumetric assessments. Since then many fields have been explored and the installed geothermal capacity has almost doubled to nearly 1,000 MWe.

Both geothermal and petroleum are underground resources for which information is scarce and hard/costly to obtain. Developers use similar physical and project/commercial steps to mitigate physical and financial development risks, e.g. see WB-ESMAP (2012) & IRENA (2015). In many countries basic geothermal and petroleum resource allocation and regulation is similar, but to some extent New Zealand is an exception to this (see also Campen&Rai-2015)

In both sectors public regulators often have to find a balance between allowing private developers freedom and commercial/information exclusivity on the one hand, and gathering central information in order to better manage and plan the public resource. Reporting requirements are an essential part of this. There are, however, also significant differences from a resource management perspective:

- In petroleum it is accepted that the resource is exhaustible (not renewing on a human time-scale) and not sustainable over the long term; royalties/resource rents are paid to compensate for this public resource not being available for future generations; hence regulators concentrate on this ownership/value

(missed future income) side to optimise returns for the public owner;

- Petroleum regulators generally leave the speed of development and level/efficiency of depletion to commercial developers (Norway is a good example of an exception as they pose more requirements – e.g. Mohn&Osmundsen, 2008, Kreft et al., 2014);

- Petroleum resource/reserve assessment for regulators is therefore generally focused on the financial/royalties implications; and as oil prices can fluctuate rapidly with significant financial implications, petroleum reserve reporting is generally frequent (at least annual) and a large degree of global harmonization has taken place (especially the latest version of SPE-PRMS, 2011);

- Geothermal, on the other hand, is generally seen as a clean and sustainable resource. Royalties/resource rents are not very common (or high) for geothermal energy in most countries. Instead, in many countries geothermal generation receives subsidies or other support on the basis of its renewability, sustainability and/or status as a local indigenous resource (replacing fossil imports);

- Geothermal resource/reserve reporting is generally more focused on proving/demonstrating the long-term sustainability to regulators (e.g. in the cases of Iceland and New Zealand, see Campen&Pettursdottir, 2016) and concentrates on the moment of consenting;

- In geothermal only recently attempts have been started to harmonize resource/reserve reporting standards (AGEA-2010, UNFC-2009 with 2016/17 IGA-Geothermal Specifications in the making);

New Zealand has recently (2008-2013) gone through a major enhancement of its petroleum regulations and reporting requirements. It also has more than 60 years of geothermal production and reporting experience and one of its main regulators recently started a discussion to improve/harmonize geothermal reserve reporting in NZ (WRC-Maunder, 2014) as part of its 10-yearly Regional Plan Review starting in 2017. Both cases can provide lessons for the future.

Section 2 further elaborates on the differences between geothermal and petroleum resources and different interpretations of sustainability in this context.

Section 3 then goes into the specific New Zealand geothermal (RMA) and petroleum (CMA) regulations, reporting requirements and recent changes.

Section 4 derives some conclusions from these comparisons

2. GEOTHERMAL VS PETROLEUM RESROURCE MANAGEMENT & REPORTING

2.1 Depletable vs sustainable resource management

Whereas petroleum resources are generally managed from the perspective of maximizing the (financial) return for society for the loss of future, depletable resources (e.g. through resource rents and royalties), geothermal energy is a sustainable, renewable energy resource and generally does not attract royalties; altering the basis for public resource management.

However, in practise – for economy-of-scale reasons - many geothermal power plants extract heat faster from targeted reservoirs than natural recharge replenishes it, leading to a gradual depletion. Most geothermal systems will regenerate in a similar (human) timescale if left to recover. This means that for adequate, sustainable resource management it is important (even more so than for petroleum resources) to assure the accurate, on-going assessment of the resource. Clarity on what 'sustainability' means is an important prerequisite to understand further geothermal resource management requirements.

Much of the discussion around 'sustainable development' goes back to the publication of the Brundtland Report of the United Nations (World Commission on Environment and Development, WCED, 1987). The Brundlandt Report (1987) brought earlier 'natural' themes together with notions of 'fairness (both between parts of the globe and generations), popularized the concept on a global scale and became the starting point for subsequent international (e.g. Rio-1992 and subsequent Climate Change debate) and national policies. The Brundlandt Report states: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Since then the concepts of 'sustainable development', 'sustainability' and 'sustainable management' have been extensively used in national and international environmental debates, with multiple interpretations.

At times concepts of renewability and sustainability have been used interchangeably. In this paper, we'd like to keep to a rather strict separation (e.g. Stefansson, 2000), whereby 'renewable' describes a property of the resource: regeneration – generally seen on a human timescale. While 'sustainable' applies to the use of the resource, so a 'continuous sustainable yield can be obtained'. He applies this to the examples of two resources which are in principle renewable: geothermal energy and fisheries and concludes: 'in order to obtain sustainable exploitation of an energy resource, the resource has to be renewable. Sustainable operation is characterised by some kind of equilibrium. For a long time operation, it is not possible to extract more energy out of the system than the amount of energy entering into the system. Therefore, sustainable exploitation can only be obtained from renewable energy resources." He

doesn't, however, further define the 'interlying grey area' of when and in what timeframe (or spatial distribution) an equilibrium can be called 'sustainable'.

Luketina (2012) applies to geothermal resources a similar discussion on strong vs. weak sustainability as developed by Solow (1974): 'Sustainability can refer to either weak or strong sustainability. Strong sustainability requires no loss of natural resources, and thereby provides future generations with at least the opportunities of today's generation. However, weak sustainability allows the depletion of some natural resource stocks, as long as future generations will still be at least as well off as today's generation, through technological change and the like. Geothermal resources can be used sustainably (using a definition of weak sustainability) over any given period through controlled depletion.' This is in the context of Waikato Regional Council's geothermal policies, which have an implied timeframe for 'controlled depletion'/weak sustainability of 50-100 years for individual fields (see 3.1).

Axelsson et.al. (2005) come to a definition 'that sustainable geothermal utilization involves utilization at a rate, which may be maintained for a very long time (100-300 years). Sanyal (2005b) picks up a similar approach and 'essentially equates renewable capacity to the natural conductive plus convective heat recharge rate into a geothermal reservoir, which remains constant over geologic time (that is, tens of thousands of years) in the natural state.' He then empirically explores different levels of 'sustainable' production of existing fields with production ranging from 5 to 45 times the rate of renewal. Axelsson (2010) also defines four models of sustainable use, which could be seen as joining the 'dots' or grey areas between weak and strong sustainability (Lawless et al, 2016 implemented this and applied it to some New Zealand cases):

(1) constant production below the rate of renewal [strong sustainability – e.g. the early developments at Ngawha (5 MWe);

(2) step-wise increase in production [until a 'sustainable' equilibrium is reached – e.g. Rotokawa];

(3) intermittent excessive production with breaks [e.g. Wairakei-Tauhara in future}; and

(4) reduced production after a shorter period of heavy production [e.g. The Geysers, Ohaaki].

Obviously the first model represents the strongest sustainability, but at mentioned before, due to economies-of-scale most large-scale geothermal projects around the world are extracting heat and fluid at a faster rate than the natural rate at which these are recharged from the deeper resources below. Although lowering of temperature and pressure in the main production reservoir often increases the recharge from below above the natural rate (e.g. O'Sullivan et al. 2010), the net effect is generally still a net 'mining' of the heat resource from the reservoir rock, hence indicating finite use. The timeframes of use (50-100 years) and recharge (multiples below 10/'order-of-magnitude') are different from most petroleum of 'normal' mining projects (generally longer use and definitely shorter recharge timeframes).

2.2 Geothermal UNFC vs SPE-PRMS-code

SPE published a first one-pager Petroleum Resource Management System in 1962-1965 after a plea from banks in the USA for a consistent set of reserve definitions (DiLuzio, 2015). Over the years many updates have followed and in its latest version (2011 update) SPE-PRMS is a 250+page set of documents supported by SPE, WPC, AAPG, SPEE and SEG describing a basic reserve definition, a glossary, implementation and aggregation guidelines, as well as verification and auditing standards and examples of reserve reporting cases (conventional and unconventional) over the lifetime of projects. The primary aim of SPE-PRMS is to report with more clarity the volumes of petroleum that can be commercially recovered from a reservoir in the future, and the related uncertainties. The PRMS incorporates a central framework that categorizes reserves and resources according to 2 dimensions: the *level of (geological) certainty associated with their recoverable volumes (horizontal axis in the figure below)*, and classifies them according to the potential for reaching commercial producing status (*vertical axis*). The method is in principle project based, but guidelines have been developed to facilitate aggregation into company portfolios, and the method has been used by many regulators.

The geothermal sector has suffered from a lack of clear, harmonized geothermal reserve reporting standards for a long time (e.g Lawless et al, 2016; IGA, 2015). In 2008 and 2010 a combined Australian/Canadian Geothermal Code (AGEA, 2010) was developed (similar to the mining-CSIRO-code), that received some global use (including in World Bank-projects, e.g. for the classification of national geothermal resources of Nicaragua). In 2014 WRC proposed a modified version of this 'Australian Code' to be used for reporting of NZ geothermal resources in the future. In the meantime the International Geothermal Association (IGA) and UNECE are finalizing Geothermal Specifications to go with the general UNFC-2009 Resource Classification Framework. This is to replace the existing 'Australian Code', which is not being maintained anymore. Both geothermal codes/frameworks have a clear relation to SPE-PRMS classifications. The UNFC-2009 Framework is somewhat more complicated, but maps well with the SPE-PRMS code (see Annex-1)

3. NEW ZEALAND: RMA-GEOTHERMAL VS CMA-PETROLEUM

In New Zealand geothermal and petroleum resources are regulated by different laws/acts (RMA and CMA respectively – see below), leading to different resource management and reporting regimes, among others.

3.1. NZ-RMA-Geothermal

New Zealand was one of the first countries to develop its geothermal resources (starting with Wairakei in the 1950s). The Resource Management Act (RMA, 1991) 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 Water & Soil Conservation Act (WSCA-1967). 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 liquid volume per day/year (rather than GJ or MWe) as the 'consentable unit'.

In New Zealand geothermal water/energy (unlike most other petroleum or mining resources) is not specifically owned by the Crown, land-owner or any other party, with some contention around this subject (see Lawless, et al. 2016). "Under the RMA sustainable management of geothermal water/energy is the responsibility of regional authorities. In New Zealand's Taupo Volcanic Zone (TVZ, where more than 90% of know geothermal resources are) these regional authorities are the Waikato Regional Council (WRC) and the Bay of Plenty Regional Council (BoPRC). Access to the geothermal resource also requires agreement with the land owner. " (Lawless et al. 2016).

The Resource Management Act 1991 (RMA) is a wide-ranging act that regulates access to and use of natural and physical resources such as land, air and water, with sustainable management of these resources being the overriding goal. Each regional council must have a Regional Policy Statement (RPS), which must identify the main resource management issues in the region, and then provide policies and methods to achieve the integrated management of these resources (land, water, geothermal, etc.). Each regional council may also develop a Regional Plan, which provides the more detailed rules about the use of natural and physical resources (Luketina, 2010). These policies and plans have to take into consideration several requirements of the Act itself, the accumulation of case law (especially of the hierarchical Environment Court and High Court) and relevant central government directions through National Policy Statements (NPS), especially the NPS on Renewable Electricity Generation (2011). Development of a Regional Plan is a public process and the geothermal aspects have attracted significant public submissions from a variety of groups, as well as appeals to the Environment Court. Regional Plans must be reviewed (at least) every 10 years.

3.2. Further defining sustainability – RMA: resource and effects

RMA has sustainable management at its core, which is defined in: Part 2. Section 5 (author's bold):

(1) The purpose of this Act is to promote the sustainable management of natural and physical processes.

(2) In this Act, "sustainable management" means **managing the use, development, and protection of natural and physical resources in a way, or at rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while -**

(a) **Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations**; and

(b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

(c) Avoiding, remedying or mitigating any adverse effects of activities on the environment."

It is the resources part (2a), which is of most relevance to our discussion. When considering a consent application for a (geothermal) project, application of Section5 involves an overall 'broad judgment' as to whether the proposal will promote the sustainable management of natural and physical resources in the light of other benefits to society/community (like employment, economic development, etc).

Section 2 of the RMA further defines energy produced from geothermal sources as renewable energy and in 2004 two sections were added (Miller, 2011):

- section 7(j) requiring particular regard to be had to 'the benefits to be derived from the use and development of renewable energy'. These benefits include "a reduction in the use of fossil fuels for electricity generation and hence a reduction in greenhouse gas and some other emissions and its reliability independent of climatic conditions." (Luketina 2010). This is further reinforced by the NPS on Renewable Electricity Generation (2011).

- Section 7(l) requiring similar regard to 'the effects of climate change';

Many publications (including Luketina, 2010; Campen & Rai, 2015, Lawless et.al. 2016) describe details of implementation of these NZ policies further, especially for the Waikato Region (Waikato Regional Council), which contains ca. 70% of NZ geothermal resources. Implementation in Northland and Bay of Plenty regions (the two other geothermal regions in New Zealand) is very similar, but less published. As a very brief and simplified summary: geothermal systems are classified into Protected and Development Systems on the basis of natural, spiritual, economic and historic criteria. For the development systems a

certain level of 'controlled depletion' is accepted. General timeframes used are 50-100 years (i.e. multiple, 'future generations').

When applying for a resource consent, a developer is expected to 'demonstrate' the sustainable management of the resource and the avoidance, mitigation and/or remediation of external effects. In New Zealand, resource and sustainable use demonstration generally takes the form of a combination of reports on: volumetric (probabilistic) stored heat estimation, power density methods and especially reservoir modelling. Specific to New Zealand and the RMA regulation is that these reservoir reports are demonstrated using scenarios involving different fluid takes (in tonnes-per-day/year) over time horizons of ca 50 years. Resource consents are also generally specified in maximum tonnes-per-day/year of fluid take (against assumed/unmentioned enthalpies) for upto 35 years. This reflects the origin of New Zealand geothermal regulation as water (rather than energy-based) and provides some degrees of freedom to the developer on the amounts of MWe generation to install/maintain.

Implementation of the above in terms of scenarios, modelling assumptions, reporting, etc. varies per geothermal system, developer and regional regulator. Recently Waikato Regional Council commissioned a report (Maunder, 2014) suggesting the use of a common, harmonized geothermal reporting standard (in this report a modified version of the Australian/Canadian Geothermal Code was suggested), in preparation for the new Regional Plan review (geothermal variation) to be started in 2017.

Reporting and monitoring requirements are specified in resource consents and have generally been strengthened over the years: annual reports are reviewed by an independent peer review panel, who can request more reporting; generally around 'areas of concern' (often involving subsidence, seismicity, significant natural features or other external effects). Health of the reservoir is generally discussed, as well as fluid take and re-injection, pressure and enthalpy changes, but with no direct reference to (changes in) energy reserve estimates. New resource (re-)consents have been issued with 4-yearly system management plan requirements and adaptive management clauses. This is generally combined with updated reservoir models, which would give more opportunity to re-assess reserve estimate reporting.

Publication of resource/reserve estimates and other geothermal regulator reporting is mixed. Although the RMA (and the Local Government Official Information and Meetings Act LGOIMA-1987) specify the public nature of resource consent and related information, there can be reasons of commercial sensitivity (among others) to withhold such information from the public. Different regulators (and developers) interpret this differently. Waikato Regional Council (with multiple development systems and developers) interprets this more liberally, while Northland Regional Council (with 1 development system and 1 developer) and Bay of Plenty Regional Council (with 1 major development system and multiple developers) tend to interpret this in a more restricted way. There have been no challenges or appeals to the Environment Court, to provide a national comparison or 'test-case'.

3.3. NZ-CMA-Petroleum

Although traces of NZ's petroleum resources had been clear from seepages in the Taranaki region long before the European settlers arrived and the first oil well was drilled in 1865 (only 10 years after the world's first oil well in Pennsylvania), sustained exploration and development only took off in the mid-1960s (Grinlinton, 1995). Originally driven by private initiative, government involvement increased, until the Petroleum Bill 1937 'declared all petroleum in its natural condition "to be the property of the Crown" regardless of whether the land had already been alienated from the Crown or not (quoted in Grinlinton, 1995). State involvement was large until the mid-1980s when a wide-scale privatization process was initiated across the NZ economy. Although private investment in the sector was now encouraged, crown resource ownership was confirmed in the Crown Minerals Act (CMA-1991). Under the new regime there are three distinct elements in mineral exploitation and development:

- Allocation of the resource;
- Access to the resource; and
- Acquisition of land use, water and discharge consents for the environmental externalities of the mining activity."

'The purpose of minerals programmes is to establish policies and procedures to be applied to the management of Crown-owned minerals. In particular they must provide for:

- the efficient allocation of rights in respect of Crown-owned minerals; and
- a fair financial return to the Crown (resource rentals or royalties).' (Grinlinton, 1995)

Implementation of the CMA (1991) has been through various, subsequent Mineral or Petroleum Programmes (starting in 1995). In general these programmes have been rather light-handed in terms of information requirements and reporting standards in comparison to similar jurisdictions until recent changes (CMA, 2013; see below). New Zealand having the 8th largest Exclusive Economic Zone in the world and promising geological structures and prospectivity, however, is still quite under-explored and has only established production in one area/basin (Taranaki on-shore and shallow-offshore). Detailed accounts of the background and possible reasons can be found in Grinlinton (1995) and MBIE (2012). It also had and has a relatively good public perception of its regulation and royalty's regime (e.g. see Fraser Institute, 2014).

With the National government coming into power in 2008, there was a drive to attract more investment to

the minerals sector (especially petroleum) to 'maximize gains for NZ Petroleum Reserves' (MED, 2010). Subsequently a lengthy process of studies and consultation rounds resulted in wide-ranging changes to CMA in May 2013, and subsequently the NZ Petroleum and Minerals (NZP&M) Petroleum Rules & Regulations (2014), as well as environmental, health and safety and other related regulations. These also included changes in reporting requirements, as well as open publication of these. The reasons and implementation of these can be instructive for the geothermal sector. The below gives a general overview of the aims and implemented changes as well as their results, giving a picture of the overall changes, but concentrating on the reserve and resource reporting requirements, as well as additional measures to improve the government's ability to understand and manage the NZ petroleum estate.

3.4. Changes in Petroleum Reporting & Publication in NZ

After the changes to the CMA and NZP&M Rules & Regulations, NZ changed from the original, more liberal reporting and publication system (more akin to USA and Australian model) to a more 'controlled' UK/Norway NorthSea-model (see also table 1).

Table 1: Reserve reporting & publication before and after CMA-2013-changes.[1]

	Information required to be reported by developers								
	STOIIP	GIIP	Est recoverable Oil & Gas	Cumulative recovery	P90	P50	P10	Contingent resources	Prospective resources
NZ (before CMA changes 2013)	yes	yes	yes	yes	yes	yes	no	no	no
UK	yes	yes	yes	yes	yes	yes	yes	partially	partially
NZ (after CMA changes 2013)	yes	yes	yes	yes	yes	yes	yes	yes	no?
Norway	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Information publically available								
NZ (before CMA changes 2013)	no	no	yes	yes	no	yes	no	no	no
UK	no	no	yes	yes	yes	yes	yes	yes	yes
NZ (after CMA changes 2013)	yes	yes	yes	yes	yes	yes	yes	yes	*gov/GNS extimates*
Norway	no	no	yes	yes	no	yes	no	yes	yes

As can be seen from Table 1, apart from requiring more data to be reported, much more of this information is to be made publically available.

- Apart from this, specifications for the reported information were enhanced (e.g. specific reference was made to SPE-PRMS standards of reserve reporting, while in the past a more generic 'industry standard approach' was specified);
- More personnel were added to enhance verifying and – if necessary – questioning of the reports and data being sent in to assure consistency and accuracy;
- Reporting frequency (for most categories) was reduced from 6-monthly to annually;

All of the above was intended to provide more transparency and clarity of information for the government and the public to be in a better position to manage and plan the use of its resources and related royalty streams. This is also visible in the data published annually by MBIE both on aggregate (see table 2) and field level.

Table 2 NZ Petroleum reporting & publishing 2009-2015

	Remaining Reserves (1P-P90) as at 1 January xxxx	Remaining Reserves (2P) as at 1 January xxxx	Remaining Reserves (3P) as at 1 January xxxx	Contingent (2C) Resources
	PJ	*PJ*	*PJ*	*PJ*
	Oil & Condensate			
Oil-2009		*1,105*		
Oil-2010	*653*	*983*		
Oil-2012	500	900		
Oil-2013	482	885		
Oil-2014	396	826	1,042	260
Oil-2015	589	682	861	74

The new reporting system in New Zealand has only been in operation for 2 years, which is too early to evaluate properly. However, a similar exercise in The Netherlands, was described and evaluated after 5 years of continuous use (Kreft et al, 2014), with as one of the main conclusions: 'Implementing and maintaining PRMS is an extensive but worthwhile task. The power of PRMS lies in multiple years' annual reporting and analysis. [..] PRMS and project attributes allow analysis and future planning of the hydrocarbon maturation process in The Netherlands.'

[1] STOIIP and GIIP are terms that stand for Oil/Gas Initially In Place, which are reported to provide a baseline/anchor for changing estimates of future recoverable reserves/resources: did these change due to change technical information, on-going production, market circumstances or otherwise. Estimated Ultimate Recoverable (EUR) similarly helps to identify and double-check sources of changing estimates.

3.3. Regulation and reporting comparisons

Despite the absence of a clear, harmonized geothermal reserve reporting framework, NZ geothermal resource reports (in terms of 'sustainable' resource overview as the regulator/WRC requires them), would seem to largely correspond to the cumulative of identified/reported 'reserves' on the one hand (for those development systems that have been drilled, producing and modelled with reservoir simulations and granted resource consent applications); and contingent/prospective resources for many/most of the others: contingent, because most TVZ resources have been 'drilled' or are otherwise rather well defined; not contingent (but 'prospective/unrecoverable') as some of these resources have no development permission or are specifically protected from development.

A comparable identification and aggregation of geothermal resources is deemed necessary, as the New Zealand (WRC) sustainable geothermal development policy depends on 'some resources being protected (for future generations), while/some other resources can be depleted in a controlled manner'. This amounts to a type of 'spatial/resource planning approach', one which is also suggested for coastal marine management in NZ. Annex-1 gives an overview of a (one-off) estimate of TVZ geothermal resources if reported under UNFC-2009. This would have to be updated on a regular basis to provide the kind of value that PRMS provides to the petroleum regulator (see 3.2).

Table 3 Differences Petroleum (CMA) vs Geothermal (RMA) (source: BoPRC, 2010 and author's findings, 2016)

	CMA-Oil and Gas	**RMA-Geothermal**
Resource exploration & production licensing	Exclusive license for exploration for a set period	Open slather until exclusive consent granted, which cannot be granted without information to advise of likely effects (can therefore be somewhat chicken and egg); Private access deals/contracts with land-owner
Resource allocation ***principle***	Run down resource; royalties to pay for use/run-down of public resource (not available/economic loss to future generations)	Sustainable use to be available for future generations
Resource policy and planning	NZ had a mixed 'open acreage' + auctioned regional tender process. Now more focused on regional auctioning.	Clear regional geothermal resource planning policy (in Waikato; BOPRC 'harmonizing' its policies) based on the whole portfolio; some fields classified as 'protected' (for future generations), while/so others can be classified for development and 'controlled depletion' (Axelsson-2-3-4)
Resource allocation ***process***	Single user	Multiple users per field are/have to be allowed
Resource allocation ***effects***	No significant surface features. Must account for impact on environment	Must account for impacts on surface features and ecologies/environment
Environmental impacts of processes	Done through RMA	RMA accounts for all environmental externalities of processes, as well as resource principle & allocation
Treaty of Waitangi implications	None	Geothermal is regarded as 'Taonga' (treasure) with various RMA-process and consultation implications
Resource proving and reporting	Resource proving limited, but annual reporting according of resource & reserves (changes) to strict guidelines (reporting requirements increased in 2012/13); - (after CMA-2013): Consistent method to link and aggregate reported 1P-2P-3P&2C reserves/resources to overall aggregate; - Used for long-term resource (royalty) planning -Justified on basis of 'public/crown resource' and royalties stream - Much additional, 'original' data (incl drill cores & data, geophysics/ seismic, chemistry, etc	- Strict resource 'demonstration'/ proving at time of RMA-consent, but different methods (no standardized method yet); - Annual reporting but more on effects than on the energy resource; - No clear link back between developer reserve reporting and WRC/TVZ aggregate, sustainable resource overview; - Justified on basis of public resource and sustainability; - More reports can be requested by Council and/or PeerReviewPanel, but generally very limited 'original' data; - Much old data exists from 1960-80s government drilling campaigns, but not all publically accessible (or to Regional Councils)
Publication	- Publication of reserve data much more open since CMA-2013; - Public access to other 'original' data generally restricted with delay clauses of (at least) 5 years	- RMA-1991 and LGOIMA-1987 have specifications for public transparency and reporting, but implementation /interpretation differs per regional council

4. CONCLUSIONS

1. Despite the differences in background and aims (sustainable vs finite resources) and regulation base (RMA-water-sustainability based; CMA-energy-ownership-property-based), the geothermal and petroleum sectors (in NZ) have much in common in terms of the need ánd difficulty in gathering information. Monitoring and (reserve) reporting are an essential part of this;

2. In the petroleum sector there has been a long history of global harmonization/standardization of reserve/resource reporting methods, especially around SPE-PRMS (2011). Since 2008 New Zealand has significantly 'beefed up' its petroleum reserve reporting requirements, in terms of information required and public availability as well as specifications for reporting (largely based on SPE-PRMS now). In addition, a significant expansion of staff was intended to assure that the regulator/administrator (MBIE/NZP&M) has both the expertise and man-power to verify and follow-up on this data. This has enabled a better management and estimation of future petroleum production (and royalty/tax income) for New Zealand (as a similar exercise had done for The Netherlands; see: Kreft et al, 2014);

3. In geothermal, only recently there have been efforts towards such harmonization (AGEA-2010, UNFC-2009-Framework with IGA Geothermal Specifications). The UNFC-2009 Framework is more nuanced and slightly more complicated than the SPE-PRMS or the Australian Code. There could be some questions whether that additional level of 'nuance' is warranted by the uncertainties inherent in geothermal (or petroleum/mining) project development and whether 'additional nuance' could also become a source of confusion; and hence make understanding and acceptance by the global geothermal community (especially regulators and investors) potentially more challenging. Both methods 'convert/map' easily to SPE-PRMS, which will help acceptance, as many investors/developers are either petroleum companies or electricity companies with gas portfolios; hence PRMS is better known to them.

4. In more than 60 years of geothermal development much experience has been gained with resources assessment, reporting and monitoring in NZ. Generally resource assessments are based on a combination of (probabilistic) volumetric stored heat calculations, power density methods and especially computational reservoir simulations. Reserve/resource reporting in reality only really happens at the moment of consenting, and after that is generally not revisited, as long as the developer stays within production/license conditions. Assessment differs per field, developer and (regional) regulator. Recently WRC has put out a discussion document (Maunder, 2014) to suggest a more harmonized reporting approach, based on a modified AGEA-2010. This in preparation of the review of WRC Regional Plan (Geothermal Variation) to start in 2017;

5. Petroleum reserve reporting in NZ is on an annual basis, which fits the highly volatile petroleum market. As electricity markets (NZEM) generally have more stable medium-term prices, a lower frequency of reporting would be suggested for geothermal. In NZ this could be once in 4 years to coincide with the obligation to produce 4-yearly System Management Plans and the correlated updating of reservoir models;

6. Comparing geothermal to SPE-PRMS also reveals the useful reporting categories of OIIP/GIIP (Oil/Gas Initially In Place) and EUR (Estimated Ultimately Recoverable) as useful 'anchors' for on-going Resource and Reserve reporting. A comparable Stored Heat Initially In Place (SHIIP), should be easy to derive from Volumetric Assessment and Reservoir Models alike (the main geothermal estimation methods at different project stages);

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Annex 1: NZ Geothermal Resources according to UNFC-2009&PRMS Classifications

SPE-PRMS classes	Inventory, exploration proiects, Resource + Reserve (cumulative)	Measured & Indicated Resource + Reserves (cumulative)		Proven Reserves
UNFC-2009 Classes	**E3 - F3-4/G4 - Exploration Projects; additional resources**	**E2-F2/G1-2-3 - potentially commercial projects and upside to existing commercial projects (publically 'stated')**		**E1/F1/G1-2: Commercial and Consented Projects**
NZ Geothermal Field/System	30 Yr-Capacity median/best estimate based on SKM/WRC & NZGA (2001/2)	New Public Data 2015	Resource+ reserve (cumulative)	Producing & Committed (2015)
Development Systems				
2 Horohoro	5	?	?	0
4 Mangakino	47	MRP drilled 3 wells in 2005+; temperatures were deemed OK (275 C+), but low permeability	?	0
5 Mokai	140	?	?	111
6 Ngatamariki	120	Potential upside: Proven & Probable (Grant, 2010), but potential consent/effect limits	130	82
7 Ohaaki	130	Upside: Contact indicated extra potential out of consented 40,000 tpd;	85	60
10 Rotokawa	300	?	?	175
11 Wairakei-Tauhara	830	Tauhara-II consented for x tpd - basis for stated 250 Mwe, but not being developed at the moment due to electricity market conditions. Might be developed in stages.	600	383
Ngawha - Northland RC)	75	+50 Mwe recently consented (but appealed)?	85	35
Kawerau (EBOP)	450	EBOP: 176,000 tpd allocated/consented, but only 110,000-120,000 used; hence: 'consented margin' of ca 1/3rd?	188	145
Rotoma (EBOP)	35	?	?	0
Roturua (EBOP)	35	?	?	?
Tikitere-Taheke-Ruahine (EBOP)	240	?	?	0
Totals for Development Systems	**2,407**		**1,374**	**991**
Limited Development Systems				
13 Tokaanu-Waihi-Hipaua	200	NZGA (2014)/Lawless(2005?): developable to 199 Mwe	? No interest?	0
1 Atiamuri	6	NZGA (2014)/Lawless(2005?)" env limitatiions	0	0
Research Systems				
9 Reporoa	42		?	0
Protected Systems				
3 Horomatangi	**380**		0	0
12 Te Kopia	**96**		0	0
14 Tongariro (ketetahi)	**100**		0	0
8 Orakei-Korako	**110**		0	0
15 Waimangu	**280**		0	0
16 Waiotapu-Waikite	**340**		0	0
Ketetahi (EBOP)	**100**		0	0
Totals All Systems	**4,061**			

PRMS vs UNFC-2009 Resource and Reserve Categories

PRMS Class		UNFC-2009 "minimum" Categories			UNFC-2009 Class
Discovered	Reserves	E1	F1	G1,G2,G3	Commercial Projects
	Contingent Resources	E2	F2	G1,G2,G3	Potentially Commercial Projects
		E3	F2	G1,G2,G3	Non-Commercial Projects
	Unrecoverable	E3	F4	G1,G2,G3	Additional in Place[a]
Undiscovered	Prospective Resources	E3	F3	G4	Exploration Projects
	Unrecoverable	E3	F4	G4	Additional in Place[a]

[a] Additional quantities in place associated with known deposits (discovered) and with potential deposits (undiscovered).