Classification and Reporting Requirements for Geothermal Resources

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ABSTRACT

Growing awareness and interest in renewable resources has raised the need to homogenise the reporting requirements for geothermal resources so that they can be applied worldwide. As no globally agreed standards, guidelines or codes exist, there remains too much latitude in geothermal assessment, which leads to increased resource uncertainty, more investment risk and less confidence in development.

Reconciling the various reporting of geothermal resources is a major challenge as it is difficult to define what the target actually is: the source, the reservoir, the fluids, the stored heat, the recoverable volume, the recoverable heat, the recoverable power, or the net profit. Formulating an agreed procedure to classify geothermal resources is further complicated by changing environmental, policy and regulatory constraints around the globe. Present day techniques of computing geothermal resources provide only ballpark estimates at best.

This paper addresses the existing gaps in standardising geothermal resources assessment and reporting by capturing: current methods used to identify potential geothermal projects; current practices in classifying and reporting geothermal resources and reserves; key decision parameters for operators, investors, governments and insurance companies; and current obstacles to a common and transparent way to secure investment in geothermal energy.

1. INTRODUCTION

Classification of geothermal resources and systems can initially be related to their geothermal energy potential. This can be assessed according to the final use: direct use and district heating systems (use hot water from springs or reservoirs near the surface), geothermal heat pumps (use stable ground or water temperatures near the earth's surface to control building temperatures above ground), electricity generation in a power plant (requires water or steam at relatively high temperature), or combinations of the above.

In estimating either resources or reserves, one should specify the assumed economic conditions and technology, which in turn depend on the use for which the geothermal potential is intended.

2. FUNDAMENTAL CHALLENGES

There are fundamental differences in prescribing a classification system that depend on whether it aims at being a reporting standard, a set of rules, a set of guidelines, a set of definitions, a code or a protocol. Each of the above options carries a substantially different ability to reinforce the goal of reducing the uncertainty in defining the value of a given geothermal resource and thus, the risk to investors.

It is also a challenge to develop a system that can equally satisfy the requirements of different potential end users of the same geothermal resource: governments, field owners, operators, investors, reserves auditors, insurance companies, international energy associations, agencies and councils.

Defining what the actual geothermal target is, should be the first step in formulating a classification of geothermal resources or reserves. If one considers the different possible uses of geothermal energy, different investment targets are equally possible, yet they carry substantially different risks and uncertainties in their identification and estimation: the heat source, the reservoir, the fluids stored within it and/or their pressure, the temperature of the resource, the heat stored within the reservoir, the recoverable fluid volume, the recoverable heat, the recoverable power, and the net profit/revenue from a given development project.

Interestingly, the geothermal community cannot agree on a common definition for Enhanced (or Engineered) Geothermal Systems (EGS), which are currently

regarded as holding considerable geothermal resources.

According to the MIT definition (2006), these are "*engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources. For this assessment, we have adapted this definition to include all geothermal resources that are currently not in commercial production and require stimulation or enhancement. EGS would exclude high-grade hydrothermal but include conduction dominated, low-permeability resources in sedimentary and basement formations, as well as geopressured, magma, and low-grade, unproductive hydrothermal resources. In addition, we have added coproduced hot water from oil and gas production as an unconventional EGS resource type that could be developed in the short term and possibly provide a first step to more classical EGS exploitation*".

On the other hand, according to the European Geothermal Energy Council (2012), "*An EGS is an underground reservoir that has been created or improved artificially*".

It is obvious that, without an unambiguous understanding of what a given type of geothermal resource is, it is impossible to succeed in issuing universal classification and reporting standards for this resource type.

In what follows, a summary of the main classical approaches to identifying and defining geothermal resources and reserves is presented.

3. REVIEW OF PAST AND PRESENT CLASSIFICATION APPROACHES

In this section, reference is made to the review of De Witt et al. (2011), which is further extended here to include other relevant classification approaches. Yet, this review is not meant to be exhaustive, but aims at capturing the main logical criteria adopted so far towards geothermal resources classification.

2.1 By Accessibility and Discovery Status

Muffler and Cataldi (1978) defined the resource base as "*all the thermal energy in the earth's crust beneath a specific area, measured from local mean annual temperature*".

As illustrated by the McKelvey diagram in **Fig. 1**, only a part of this so-called geothermal resource base can actually be technically and economically exploited.
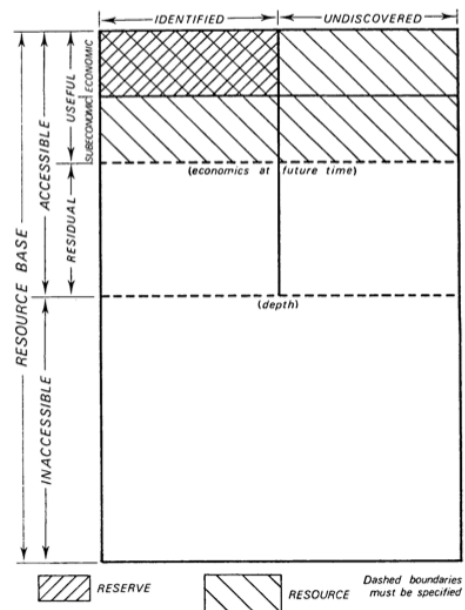

Figure 1: McKelvey diagram for geothermal energy (Muffler and Cataldi, 1978).

2.2 By Temperature, Use, Type and Status

Although it is physically possible to use high-temperature geothermal systems for other uses, it is generally more valuable to generate electricity from them. Having noted this, it is also often technically possible to generate electricity from a low-temperature reservoir, depending on the type of plant used for this purpose (flashed steam plant, dry steam plant, binary power plant, hybrid power plant, etc.). In response to this, some resource definition approaches have tried to define a temperature cut-off for different uses.

Richards et al. (2008), for example, reported that the Geo-Heat Center at the Oregon Institute of Technology had devised a simplified classification system, where a temperature cut-off is applied to determine the final use that can be made of a given geothermal occurrence. Bromley (2009) presented a table that grouped geothermal resources based on the following factors: temperature (high/low), use (direct/electricity), type (within each "use" category) and current status (existing, planned, potential and market).

Yet both of these approaches fail to account for other critical parameters which might justify better a geothermal play development. For example, a temperature cut-off gives information on heat content regardless of other physical properties (e.g. permeability, porosity, geochemistry, thermal capacity and conductivity).

2.3 By "Potential"

According to Ryback (2010) (see **Fig. 2**), the *theoretical potential* describes the physically usable energy supply (for geothermal: heat in place). Due to technical, structural and administrative limitations only small fractions of the theoretical potential can

actually be used. The *technical potential* describes the fraction of the theoretical potential that can be used under the existing technical restrictions (currently available technology). Since this potential depends mainly on technical boundary conditions it is less subject to temporal variations than the economic potential. The *economic potential* describes the time and location dependent fraction of the technical potential that can be economically utilized within the energy system under consideration. Several economic boundary conditions exist (e.g. oil price changes, changing taxations, write-offs, feed-in tariffs). The *sustainable potential* is a fraction of the economic potential; it describes the fraction that can be utilised by applying sustainable production levels. The *developable potential* describes the fraction of the sustainable potential that can be developed under realistic conditions (regulations, environmental restrictions).
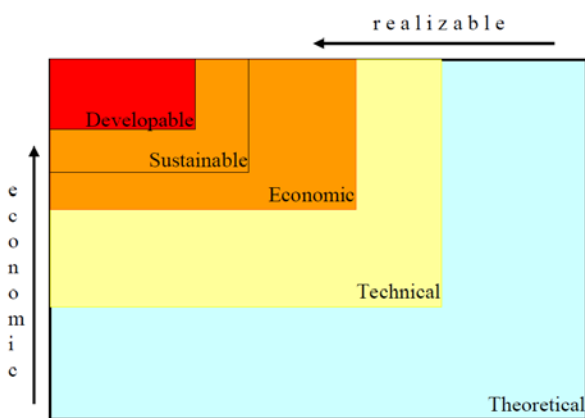

Figure 2: Classification of geothermal resources by potential (Rybach, 2010)

Following on from this definition of potential, Beardsmore et al. (2010) proposed a protocol for estimating and mapping global potential specifically for EGS systems.

Goldstein et al. (2011) adopted the classification approach by potentials and complemented it with estimated figures to try and capture the global geothermal resources.

Unfortunately, as pointed out by Rybach (2013), the generic term *potential* is often used in the public domain, without clear indication of what particular type of potential (theoretical, technical, economic, sustainable or developable). This carries the risk of generating confusion among the investors as to the actual expectations from a given geothermal prospect or development. Rybach also highlighted that reliable values for the recovery factor are needed to convert theoretical potentials into technical potentials, but *"there is hardly any solid data about them, not even for hydrothermal systems, let alone for petrothermal/EGS"*.

2.4 By Stored Heat

The *heat in place* approach was developed by Nathenson (1975), White and Williams (1975), Muffler and Cataldi (1978) and Muffler (1979), and quickly became a well-established method for the assessment of geothermal resources in the United States (Lovekin, 2004). This approach consists of estimating the thermal energy available in a volume of porous and permeable rock, given the thickness, areal extent, porosity, average temperature, rock density and specific heat of the rock in the reservoir, and physical properties of fluids. These estimates require data to be collected or calculated using adapted correlations. Both deterministic and probabilistic approaches can be undertaken.

Classifying geothermal resources on the basis of the heat in place only leads to large figures that may be misunderstood by non-specialists, who may wrongly interpret them as recoverable energy. On the other hand, when the process to be implemented to recover a given resources is still unknown or highly uncertain, the heat in place may represent the only reference estimate.

2.5 By Electric Power Generation Potential

The stored heat can then be used to assess the electric power generation potential of the identified geothermal occurrence. For electric power generation projects, the potential is a function of the thermal energy stored in the reservoir, the thermal energy that can be recovered at the wellhead and the efficiency with which the latter can be converted into electric power. The latter's potential can be estimated from the stored heat through the application of a recovery factor, an energy conversion factor, a power plant capacity factor and power plant life.

However, as mentioned earlier, reliable values for the recovery factor are needed for the conversion of heat in place into power potential.

It should also be noted that the use of the term potential, applied to power generation that could be obtained from a given geothermal occurrence, may generate confusion *vis-à-vis* the classification system as of section 2.3 above.

2.6 By Exergy

In 1996, Lee developed the idea of applying the exergy concept to the classification of geothermal resources, based on the consideration that classification schemes relying on fluid temperature (or enthalpy) alone may be ambiguous. According to Lee, two independent properties are necessary to define the thermodynamic status of a fluid. Lee suggested that geothermal resources should be classified based on their ability to generate thermodynamic work (hence the exergy), just like calorific value is used for fossil fuels. Exergy defines the quality of the energy content within the geothermal fluid to be recovered.

In 2001, Lee defined his classification method as robust and insensitive to both pressure variations of the geothermal fluid (at constant enthalpy) and surface conditions (the "sink"). His simplified exergy calculation considers the triple point of water as sink conditions, as this is when both enthalpy and entropy are null. Given that the specific exergy is sensitive to surface conditions, Lee proposed to normalise it to the maximum exergy at surface, thus obtaining the so-called specific exergy index (SExI), which varies between 0 and 1. By using the SExI on the enthalpy-entropy Mollier diagram, Lee generated a classification map for geothermal resources, which he then implemented to classify different geothermal fields worldwide based on previous literature (**Fig. 3**).
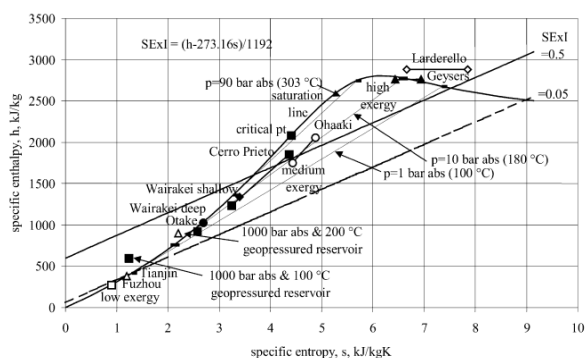

Figure 3: Examples of geothermal fields plotted on the classification map for geothermal resources (Lee, 2001)

The classification method proposed by Lee has subsequently been applied by others. Quijano (2000) performed an exergy analysis of the Ahuachapàn and Berlìn geothermal fields. Ozgener et al. (2004) and Baba et al. (2006) applied the SExI to the Balcova field in Turkey and highlighted the lack of agreement between their results and those obtained following the classification methods of Muffler and Cataldi (1978), Benderitter and Cormy (1990), and Hochstein (1990), all primarily based on temperature. Etemoglu and Can (2006) used the SExI to classify the geothermal resources of Turkey, although – in their publication – they renamed the index as specific energy rate (SER). More recently, two studies were published on the application of the exergy concept to the classification of geothermal resources in Poland (Barbacki, 2012) and in Japan (Jalilinasrabady and Itoi, 2012).

It is worth mentioning here that Lee's concept has also been applied for the quantification of global energy resources. Hermann (2006), for example, considered exergy to be a useful tool for comparing on equal grounds different energy resources of different quality (**Fig. 4**). In his opinion, exergy allows the reduction of the different properties of thermal, chemical, nuclear, radioactive and potential energies into one interchangeable currency. Thus, the exergy approach could represent a starting point for technical and economic considerations on the use of a given resource, focusing not on the raw quantity of the resource, but rather on how the way it is exploited impacts on the global system, so as to better identify and evaluate options for an energy sustainable future.

Hepbasli (2008) stated that there is a direct link between exergy and sustainable development, because exergy is the fundamental basis for the design, simulation and performance evaluation of energy systems. In his analysis, Hepbasli included different renewable energy resources, e.g. solar, wind, geothermal, biomass.
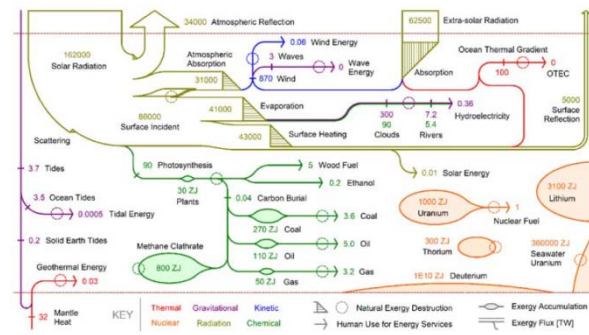

Figure 4: Global reservoirs, flux and anthropogenic destruction of exergy (Hermann, 2006)

In 2010, Ramajo et al. stated that the fluid exergy in a mature geothermal field is not only affected by natural variables, but also by anthropic factors. Thus, Lee's classification method may not be accurate under dynamic conditions as it does not account for differences between wells producing natural vapour vs. over-exploited wells. Ramajo et al. continued by proposing a new methodology to classify and evaluate the energy-exergy dichotomy by using historical data from a field in Mexico.

In 2011, Williams et al. published a review of geothermal resources classification systems and defined Lee's method as logic within the context of the use of a resource, yet of difficult acceptance by the non-specialists (less accustomed to thermodynamics terminology), and also dependent on availability of wellhead pressure and temperature conditions.

2.7 By Geological Confidence and "Modifying Factors"

The Australian Geothermal Reporting Code Committee (AGRCC) produced the first edition of its Geothermal Reporting Code and Geothermal Lexicon for Resources and Reserves Definitions and Reporting in 2008, followed by a second edition in 2010 (AGRCC, 2010a and 2010b), with the goal of providing "*a methodology for estimating, assessing, quantifying and reporting geothermal resources and reserves*". These guidelines represented the world's first uniform guide on how to report geothermal data to the market. The Code is based on the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code'), now at its 2012 edition (JORC, 2012).

4

The Code recognises three categories of geothermal resources: inferred, indicated and measured, which represents three different levels of geological knowledge and probability of occurrence. Two categories of reserves are recognised (probable and proven), based upon the likelihood and reliability of the *modifying factors* and the type of resource. The modifying factors depend on economic, environmental and political context, and assess the commerciality of the resources.

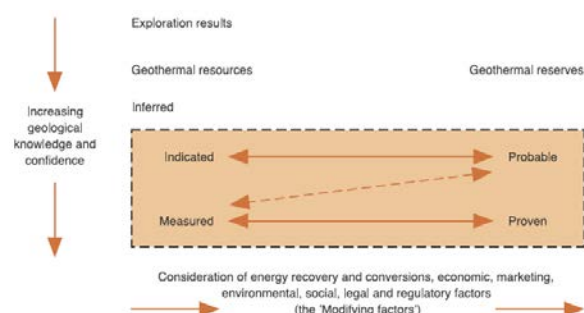The various categories are represented in **Fig. 3**.

Figure 3: Relationship between exploration results, geothermal resources & geothermal reserves (AGRCC, 2010a).

According to this approach, "*the geothermal resource is the estimated recoverable thermal energy relative to defined base and cut-off temperatures. If there is reasonable basis for doing so, convertibility into electricity may be assessed and an additional estimate of the recoverable, converted electrical energy may be stated [...]. The recovery and conversion factors used must be separately stated alongside the geothermal resource estimate, whenever it is quoted in a public report.*"

While the Code covers a minimum, mandatory set of requirements for the public reporting of geothermal resources and reserves estimates, the Lexicon provides guidance on how to estimate resources and reserves, and is of default mandatory use as the source of values for recovery factors to convert stored heat to recoverable energy.

Indeed, the same remarks already made concerning the reliability of the recovery factor estimates apply here too.

With regards to analogy with oil and gas and lessons learnt from that energy sector, the *confidence* and *probability* concepts embedded in this type of classification systems, with associated terminology such us "sufficient indicators", "more reliably characterised" and "sufficient confidence", leave room to subjectivity of the estimating and auditing exercise.

The Canadian Geothermal Code for Public Reporting was published by the Canadian Geothermal Code Committee (CGCC, 2010). Key elements of the Australian Code were adopted and/or formed the basis of the Canadian Geothermal Code for Public Reporting.

As reported by Segneri et al. (2013), the Australian and Canadian geothermal codes are still awaiting endorsement by the Australian Securities Exchange and Canadian Securities Exchanges respectively.

2.8 Others
This section includes two other classification schemes that have been proposed in the public domain.

- The Geothermal Energy Association (GEA, 2010) published the New Geothermal Terms and Definitions as a guideline for geothermal developers to use when submitting geothermal resource development information to GEA for public dissemination in its annual US Geothermal Power Production and Development Update. This guideline is not intended to be a geothermal code for publicly reporting exploration and development results in the US. It is based on identifying the resource type first: conventional hydrothermal (un-produced resource), conventional hydrothermal (produced resource), conventional hydrothermal expansion, geothermal energy and hydrocarbon co-production, geopressured systems or EGS. Then the GEA guideline requires the indication of what stage of development each separate geothermal project falls under: resource procurement and identification, resource exploration and confirmation, permitting and initial development, or resource production and power plant construction.

  It is interesting to point out that, in this scheme, the geothermal energy associated with hydrocarbon developments is not part of EGS, contrarily to the MIT definition. Also, direct uses of geothermal energy are clearly excluded from the GEA set of definitions.

- The Resource Assessment Protocol for GEOELEC (van Wees et al., 2011) is based on the work by Beardsmore et al. (2010), AGRCC (2010a and 2010b) and CGCC (2010), together with input from the oil and gas sector. It is proposed to divide it into three levels: level 1 for global European perspective resource assessment for EGS, level 2 for prospective undiscovered resource assessment for different play types, and level 3 for contingent (discovered) resources and reserves.

  This resource assessment approach is not yet fully developed in its current status of divulgation in the public domain.

4. ANALOGY WITH OIL & GAS AND LESSONS LEARNT

It is often remarked that geothermal resources are somewhat in between solid minerals and conventional fossil fuels in the way we exploit them and report them. This is why, historically, experience gained in these two sectors has been imported into the geothermal sector to draw classification and reporting guidelines. It was mentioned earlier, for example, that the Australian Code has been very much based on the JORC Code, and that the proposed protocol for GEOELEC includes input from the oil and gas industry. It is also easy to spot similarities between the geothermal resources and reserves categories proposed in the Australian Code, previously shown in **Fig.3**, and those proposed for oil and gas in the SPE Petroleum Resources Management System (SPE PRMS, 2007), shown in **Fig. 4** below.
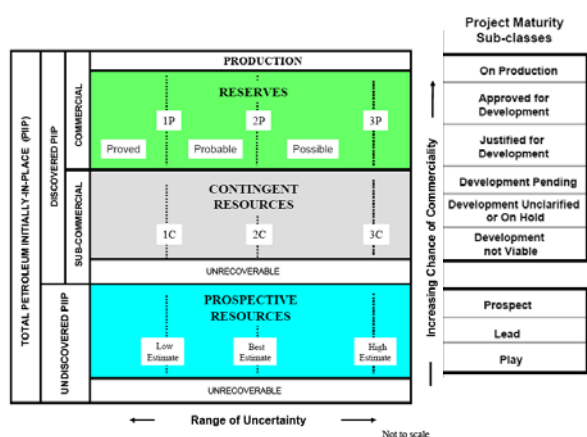

Figure 4: Resources vs. reserves relationship for the oil & gas sector (SPE PRMS, 2007).

On the other hand, it would be wrong to assume that the classification systems currently implemented in the oil and gas industry are perfect. Wagner (2009) reported a series of recent oil and gas reserves "train wrecks", where several Majors and independent E&P companies ended up writing down considerable amounts of reserves, often accompanied by the resignations of their chairmen, CFO's and CEO's. The main reason behind such events lies in the subjectivity of oil and gas reserves auditing process.

McLane et al. (2008) reported a not uncommon situation where the same dataset was given to two different (but equally reputable) auditing companies, who applied the same reporting guidelines, but with significantly different results (**Fig. 5**).

The subjectivity of the reserves auditing process is partly related to miscommunication caused by the terminology adopted in the classification and reporting schemes, where terms such as "reasonable certainty", "more likely than not", "less likely than probable" do a poor job in describing an assessment (McLane et al., 2008).
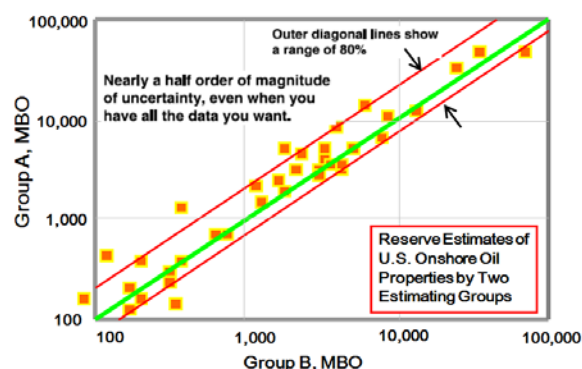

Figure 5: Subjectivity of oil & gas reserves auditing (McLane et al, 2008).

5. GEOTHERMAL HAND-IN-HAND WITH RENEWABLES?

It was mentioned earlier, in section 2.6, that the concept of exergy has already been applied as a useful tool for comparing on equal grounds different energy resources of different quality.

Recently, a group of experts - the Renewable Reserves Working Group - met in London to discuss the need to assess and quantify renewable energy resources, in a common and transparent way, to secure much needed investment for the renewable energy industry. Following a review of existing classification systems, the experts agreed that the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC) 2009 (ECE, 2010) could be applied to renewable energy resources. Deploying the UNFC to encompass renewables would allow a meaningful comparison of renewable energy resources with non-renewable resources (UNECE, 2012).

UNFC 2009 is a generic principle-based system in which quantities are classified on the basis of the three fundamental criteria of economic and social viability (E), field project status and feasibility (F), and geological knowledge (G), using a numerical and language independent coding scheme. Combinations of these criteria create a three-dimensional system (ECE, 2010) (**Fig. 6**).
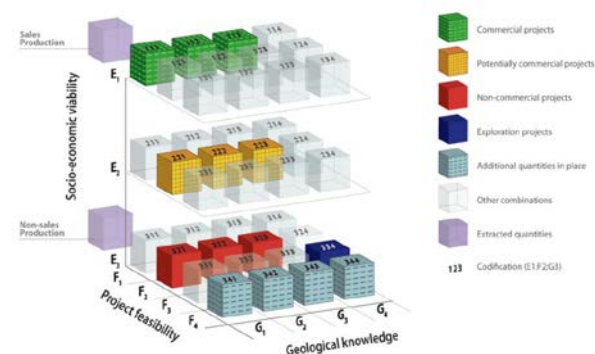

Figure 6: UNFC-2009 categories and examples of classes (ECE, 2010).

Segneri et al. (2013) already mentioned the possible implementation of the UNFC framework to include geothermal classification.

One of the main challenges towards the development of a classification and methodology for reporting all energy resources and reserves lies in the term "renewable". As stated in AGRCC (2010b), "*Geothermal resources in convective hydrothermal systems further differ from both minerals and petroleum resources by being renewable through recharge, albeit usually at a slower rate than energy is extracted. The rate of this recharge can vary significantly from system to system, and can be stimulated at varying degree by production.*" For geothermal resources, natural fluid / temperature / pressure recharge may occur, but it may not within the timeline of a given project, depending on the exploitation approach. This is an important factor to take into consideration also in the comparison between geothermal energy and other renewables in terms of resource availability.

Other challenges reside in the definition of energy system equivalence and energy price.

At the Renewable Reserves Working Group it was proposed that barrels of oil equivalent (BOE) be used as units to report and compare all energy resources, renewables included. However, there are well known issues associated with this practise, even within the oil and gas sector.

The BOE system compares the heating capacity of 1 bbl of oil (~5,800,000 BTU) versus that of 1 scf gas (~1028 BTU). However, BOE conversion factors are not unique and depend on the quality of the oil and the gas. The reported ranges are from 1 bbl oil equal to 5.6 to 6 Mcf gas, a 7% discrepancy, which can be significant when dealing with multi-million BOE deals.

Consider Bloomberg on 11-April-2013: crude oil (WTI) is trading at $93.5/bbl and natural gas (NYMEX) at $4.2/Mcf, which represents a "value conversion factor" of 22 Mcf/BOE, some four times greater than that suggested by heat equivalence.

Some argue that, as oil and gas markets do not track each other very well, there is an ever changing value conversion factor. Hence, they suggest that it may be better to adopt the more stable BTU conversion methodology, even if there is a fairly wide range of BTU conversion factors.

However, the authors believe that investors should be very careful when dealing in oil and gas assets that rely solely on the total reserves reported in BOE. An 'oil BOE' is far more valuable than a 'gas BOE' in today's market.

For geothermal energy, using BOE would be inconsistent with its recognised low CO_2 footprint versus other energy resources (**Fig. 7**) and also considering the non-transportability of heat (by pipeline or tank, for example, as it is the case for oil and gas).
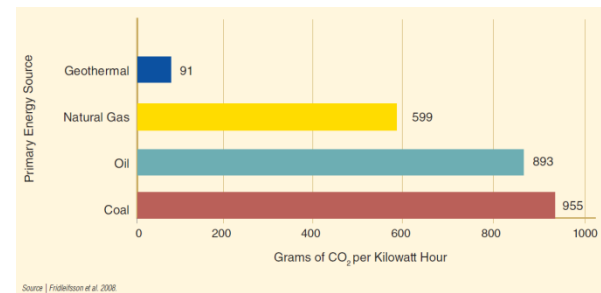

Figure 7: CO_2 emissions by primary energy source in the US (ESMAP, 2012).

This is perhaps why, in a recent survey launched among geothermal professionals (Falcone, 2013), the choice of BOE did not encounter much favour (**Fig. 8**).
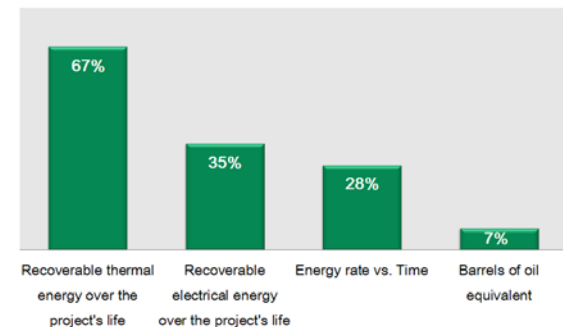

Figure 8: Survey results – how to report geothermal resources (Falcone, 2013).

6. CONCLUSIONS

At the time of writing, no universally recognised standards exist for classifying and reporting geothermal resources and reserves.

Based on past and present classification and reporting schemes available in the public domain, it can be stated that major issues remain with regards to nomenclature and terminology. Different users mean different things when referring to potential, source, resource, reserves, etc.

Lessons can be learnt from the oil and gas sector, where the subjectivity of the reserves auditing process can be related to miscommunication caused by the terminology adopted in the classification and reporting schemes.

Thus, the geothermal sector may benefit from more prescribing workflows, e.g. a deterministic (or decision tree) approach where different resource types and resource uses are handled separately, each with its own specified calculations (deterministic or probabilistic, analytical or numerical) for each specific status of project development.

7

There appear to be multiple parallel efforts within the geothermal community to try and come up with universally applicable guidelines or standards for classifying and reporting geothermal resources. Yet, the various organisations involved are not necessarily working together, which leads to duplication of the efforts and independent reference documents which – as of today – still cannot be put under the same umbrella.

In the contemporary world of global sustainable energy, there appears to be a need to compare different energy resources on equal terms, with the same units. This is an important issue, but the energy community should not rush into a system that is too generic and neglects fundamental commodity-specific aspects that have already been identified by the individual sub-communities (e.g. oil and gas, geothermal, wind, biomass and solar).

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