

Including Geothermal Energy within a Consistent Framework Classification for Renewable and Non-Renewable Energy Resources

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ABSTRACT

Growing awareness and interest in renewable energy resources, including geothermal resources, has highlighted a need to normalize the way in which renewable energy potential is reported. The renewable energy industry has become a fully commercialized sector, in which several oil and gas majors have already started to play a significant role. These players have voiced a need for a common platform to assess and compare in a transparent way the potential of their renewable and non-renewable energy portfolios. A common assessment and comparison framework for renewable and non-renewable energy resources is also needed by investors, regulators, governments and consumers as a foundation for a comprehensive overview of current and future energy sustainability scenarios at project, company, country, region or world level. As no globally agreed standards, guidelines or codes currently exist, there is currently great variability in the way geothermal potential is assessed and reported. This translates into high investment risk and low confidence in development.

This paper describes the progress made towards reconciling the specifics of geothermal resource classification with the definitions and principles of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009).

1. INTRODUCTION

It is becoming increasingly apparent that a lack of clear global guidelines and standards is holding back the assessment and development of geothermal energy as a viable energy option at a global scale. The planning and funding of future energy infrastructure on a global scale (for example, by development banks and aid agencies) is based, to a large extent, on the comparative potential of different energy options in different locations. A proper comparison of those options requires globally consistent methods for assessing and classifying energy potential. In short, there is the need to reconcile the energy potential of geothermal projects with the potential of other types of renewable and non-renewable energy projects, to provide a fair and 'normalized' evaluation framework for potential end-users.

The authority of a classification system depends on whether it is presented as a reporting standard, a set of rules, a set of guidelines, a set of definitions, a code or a protocol. These different options provide different levels of certainty (and thus risk) to investors about the estimated energy potential of a specific resource. It is a challenge to develop a classification system that can equally satisfy the requirements of different stakeholders in the same resource: governments, field owners, operators, investors, reserves auditors, insurance companies, international energy associations, agencies and councils.

Before geothermal energy potential can be objectively compared with other energy resources, a global framework is required whereby geothermal energy estimates can be objectively compared with each other. Standardized assessment methods and terminology do not yet exist for geothermal energy, but would provide a firm platform for authoritative reporting of geothermal energy potential. They would provide expert reports with a level of global endorsement and acceptance sufficient to facilitate fair comparison with other energy sources, and to ensure smooth and successful developments of economically attractive geothermal resources.

Global comparisons of geothermal potential are currently hindered on at least two fronts. Firstly, national agencies in many parts of the world have little experience and lack guidelines on how to assess, quantify and classify their local geothermal potential. The governments of developing countries often look to the capacity and price of geothermal energy in other regions and expect the same outcomes in their country. These expectations can differ greatly from expert opinions and reality. Elevated expectations have led to frustration for governments, investors and funding agencies alike. Furthermore, anecdotal evidence exists of elevated, poorly substantiated estimates of geothermal potential being used to attract investment into specific projects. Even when motives are honorable, it is not unusual for two experienced assessors to report two very different estimates of geothermal potential for the same area. This is because there is no standard level of 'confidence' for estimating or reporting potential. A low potential estimated with high confidence might be totally consistent with a high potential estimated with low confidence, but if the confidence level is not stated, then the high estimate can lead to exaggerated expectations that fail to be borne out in practice. Inconsistent estimates of potential, or elevated estimates that do not translate into sustainable production, damage the perception of geothermal energy as an investment option.

Secondly, those agencies that have assessed and classified geothermal potential within their jurisdictions have developed and used their own local methodologies and terminologies that are not necessarily comparable with, or appropriate for, other jurisdictions. Below, we review past attempts at geothermal resources classification, then introduce a resource classification scheme developed

and endorsed by the United Nations (the UNFC-2009) and discuss how it might be applied to renewable energy sources in general, and to geothermal energy in particular.

2. PREVIOUS GEOTHERMAL RESOURCES CLASSIFICATION APPROACHES

The following review, which is based on work by Falcone *et al.* (2013), is not meant to be exhaustive, but tries to encapsulate the reasoning behind the approaches proposed to date for geothermal resources classification.

2.1 By Accessibility and Discovery Status

The geothermal resource base may be defined, according to Muffler and Cataldi (1978), 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.

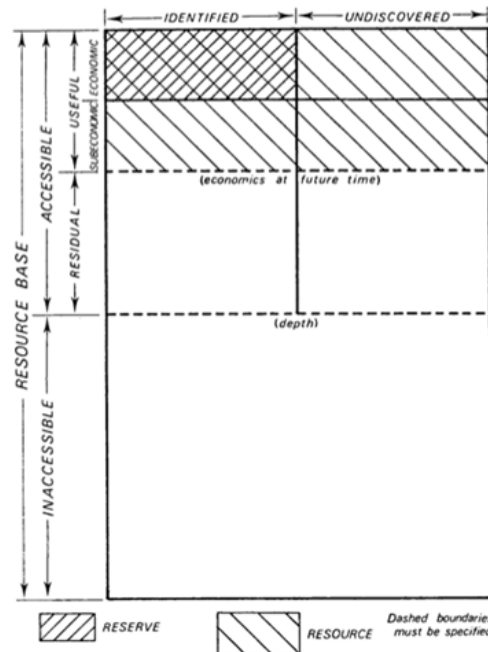


Figure 1: McKelvey diagram for geothermal energy (Muffler and Cataldi, 1978).

2.2 By Temperature, Use, Type and Status

Although it is physically possible to use high-temperature geothermal systems for other uses, greatest economic value is generally achieved by generating electricity from them. Having noted this, it is also often technically possible to generate electricity from a low-temperature reservoir (using a binary power plant, for example) but economic value is often higher from direct use of the heat.

In response to this, some resource classifications have tried to define a temperature cut-off for various uses. Richards *et al.* (2008) 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 economically optimal use for a given geothermal occurrence. Following on from the above, Bromley (2009) proposed a system that grouped geothermal resources together based on the following parameters: temperature (high/low), use (direct/electricity), type (within each ‘use’ category) and current status (existing, planned, potential and market). Unfortunately, both of these approaches fail to account for other critical factors that might better describe a geothermal development. For example, a temperature cut-off only gives information on heat content, but fails to inform the user of other crucial physical properties such as permeability, porosity, geochemistry, thermal capacity and conductivity.

2.3 By ‘Potential’

The term “potential” is used by many in the energy industry and it must be clearly defined as to what “potential” is being referred to. Rybach (2010) (see Fig. 2) states that the ‘theoretical potential’ describes the physical limitation on extractable energy supply, which in the case of geothermal energy is the total heat in place. However, because of the limitations of currently available technology and existing structural and administrative constraints, only a fraction of the theoretical potential can actually be extracted. ‘Technical potential’ describes the fraction of the theoretical potential that can be extracted under the existing technical restrictions (currently available technology). ‘Economic potential’ describes the time and location dependent fraction of the technical potential that can be economically extracted. Given that economic potential is sensitive to a number of variables such as oil and gas price trends, changing taxations, write-offs, feed-in tariffs and so on, it is more sensitive to temporal variations than the technical potential. ‘Sustainable potential’ is the fraction of the economic potential that can be extracted by maintaining production at levels that can be sustained. Finally, ‘developable potential’ describes the fraction of the economic or sustainable potential that can be developed under current development conditions (regulations, environmental restrictions, available labor force etc.).

Building on Rybach’s (2010) definition of potential, Beardsmore *et al.* (2010) proposed a protocol for estimating and mapping global potential specifically for Enhanced Geothermal Systems (EGS). Goldstein *et al.* (2011) adopted Rybach’s (2010)

classification approach and complemented it with estimated figures to try to compile and classify a global inventory of geothermal potential.

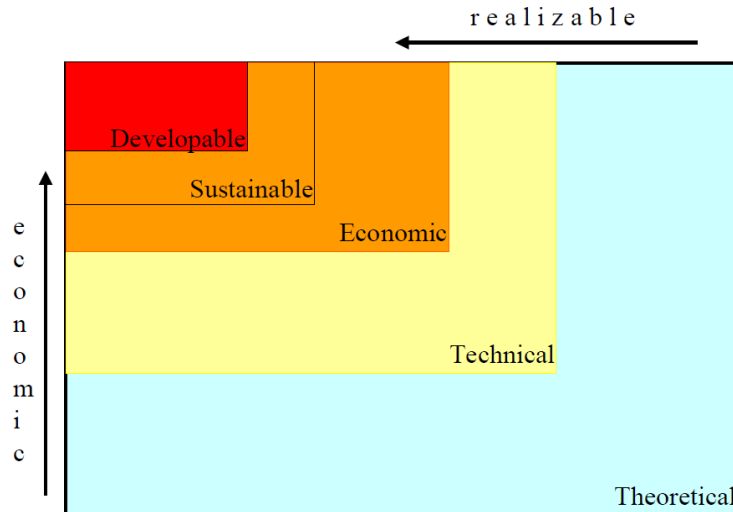


Figure 2: Classification of geothermal resources by potential (Rybach, 2010)

Unfortunately, as pointed out by Rybach (2013), the generic term ‘potential’ is commonly used in the public domain without a clear qualification of which specific type of potential (theoretical, technical, economic, sustainable or developable). This perpetuates the risk of confusing the investing community as to what performance can be expected 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 established itself as the accepted method for assessing geothermal resources in the United States (Lovekin, 2004). This technique consists of estimating the thermal energy stored 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. Both deterministic and probabilistic approaches can be followed.

Classifying geothermal resources solely on the basis of the heat-in-place leads to large figures that may be misunderstood by non-specialists as estimates of recoverable energy. This was a decisive factor in the redefinition of ‘geothermal resource’ from stored heat to recoverable heat between the first and second editions of the Australian Geothermal Reporting Code (AGRCC, 2010a). On the other hand, when the technology to recover a given resource is still unknown or highly uncertain, the heat-in-place may be the only quantity that can be reported with any confidence.

2.5 By Electric Power Generation Potential

For electric power generation projects, the potential is a function of the thermal energy stored in the reservoir, the rate of thermal energy recovery at the wellhead, and the efficiency with which the latter can be converted into electric power. Electric power generation potential can be estimated from a stored heat estimate through the application of a recovery factor, an energy conversion factor, a power plant capacity factor and power plant life. However, as noted earlier, there are few if any reliable values for the recovery factor to convert heat in place into power potential.

It should also be noted that the generic use of the term ‘potential’, when applied to power that could be generated from a given geothermal occurrence, may create confusion vis-à-vis the classification system described in section 2.3 above.

2.6 By Exergy

Lee (1996) developed the idea of applying the exergy concept to the classification of geothermal resources, to address the issue that classification schemes that rely on fluid temperature (or enthalpy) alone may be ambiguous. 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 as a basis for classifying some fossil fuels. Exergy defines the quality of the energy content within the geothermal fluid to be recovered.

Lee (2001) described his exergy-based 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 considered 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 normalize it to the maximum exergy at surface, thus obtaining the ‘specific exergy index’ (SE_{SI}), which varies between 0 and 1. By using the SE_{SI} 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).

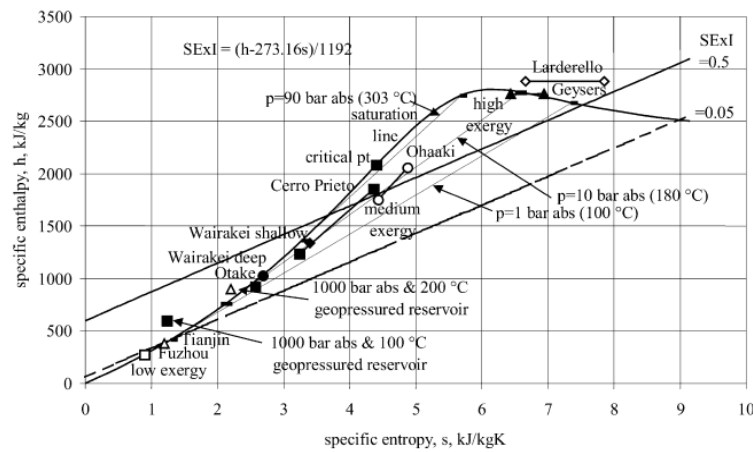


Figure 3: Examples of geothermal fields plotted on the classification map for geothermal resources (Lee, 2001)

Others have subsequently applied the classification method proposed by Lee. Quijano (2000) performed an exergy analysis of the Ahuachapán and Berlin geothermal fields. Ozgener *et al.* (2004) and Baba *et al.* (2006) applied the SEI 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 (2007) used the SEI 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 noting that Hermann (2006) employed the exergy concept to quantify global energy resources and found it to be a useful tool for providing an unbiased comparison between different energy resources of differing quality (Fig. 4). In his opinion, exergy permits the consolidation of the different properties of thermal, chemical, nuclear, radioactive and potential energies into one interchangeable currency. Thus, the exergy method may represent a starting point for technical and economic considerations on the use of a given resource. Rather than focusing on the raw quantity of the resource, the approach concentrates on method of exploitation and how this affects the global system, which should improve the identification and evaluation of future sustainable energy options.

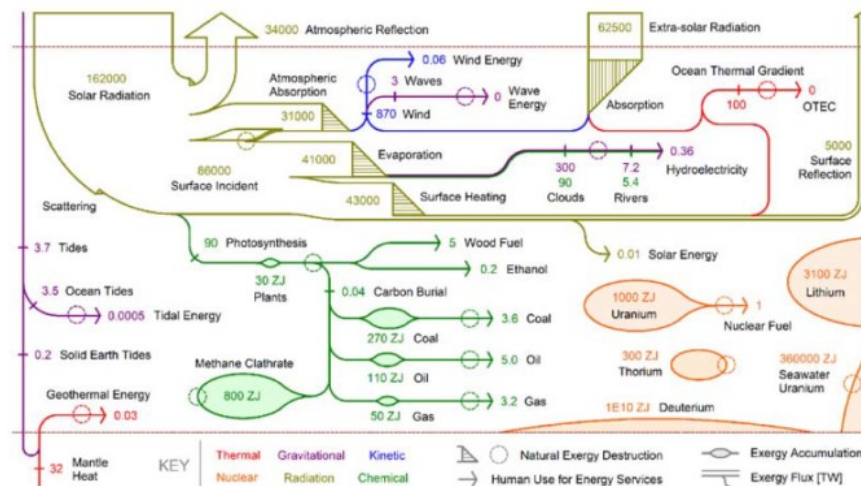


Figure 4: Global reservoirs, flux and anthropogenic destruction of exergy (Hermann, 2006)

Hepbasli (2008), who stated that exergy, which is the fundamental basis for the design, simulation and performance evaluation of energy systems, is directly linked to sustainable development, went on to use the exergy approach to analyze different renewable energy resources, e.g. solar, wind, geothermal, biomass.

Ramajo *et al.* (2010) 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 vapor vs. over-exploited wells. Ramajo *et al.* instead proposed a new methodology to classify and evaluate the energy-exergy dichotomy, presenting historical data from a field in Mexico as an example.

Williams *et al.* (2011) reviewed geothermal resources classification systems and concluded that Lee's scheme is logical within the context of exploiting a resource, yet difficult to understand and so accept for non-specialists, who are unaccustomed to

thermodynamics terminology. The use of Lee's method is also dependent on the availability of wellhead pressure and temperature data.

2.7 By Geological Confidence and 'Modifying Factors'

The Australian Geothermal Reporting Code Committee (AGRCC) produced the first editions of its Geothermal Reporting Code and Geothermal Lexicon for Resources and Reserves Definitions and Reporting in 2008, followed by second editions in 2010 (AGRCC, 2010a and 2010b). The goal of the Code and Lexicon was to provide "a methodology for estimating, assessing, quantifying and reporting geothermal resources and reserves". These documents represented the world's first uniform guide on how to report geothermal data to the market. The Code was 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).

The Code defines three categories of 'Geothermal Resources': Inferred, Indicated and Measured. These represent three different levels of geological confidence or probability of occurrence. Two categories of 'Geothermal Reserves' are recognized (Probable and Proven), based upon the likelihood and reliability of the 'modifying factors' and the category of Resources. The modifying factors incorporate economic, environmental and political variables, and influence the commerciality of the Resources.

The various categories are represented in **Fig. 5**.

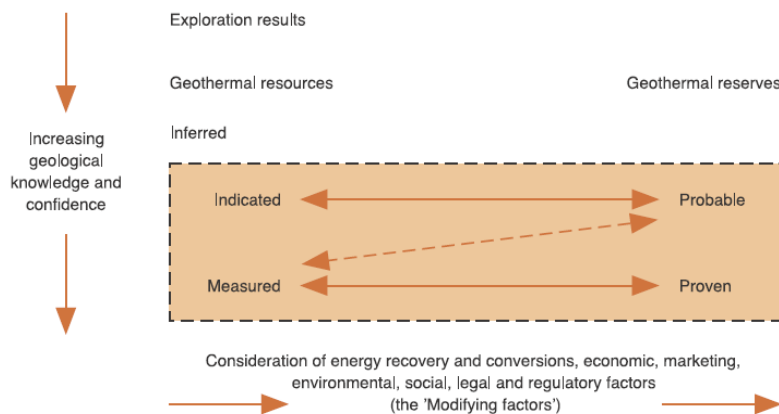


Figure 5: Relationship between exploration results, geothermal resources & geothermal reserves (AGRCC, 2010a).

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."

Where the Code presents 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. However, the same remarks already made concerning the reliability of the recovery factor estimates apply here too.

By analogy with oil and gas and lessons learnt from that energy sector, the confidence and probability concepts embedded in this type of classification system—with terminology such as 'sufficient indicators', 'more reliably characterized' and 'sufficient confidence'—leave room for subjectivity in 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.

While mandatory for member companies of the Australian Geothermal Energy Association and the Canadian Geothermal Energy Association, the Australian and Canadian geothermal codes do not carry the same weight of law with the Australian Securities Exchange (ASX) and Canadian Securities Exchanges as do equivalent reporting codes for the minerals and petroleum sectors.

2.8 Others

At least two other classification schemes 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, geopressed systems or EGS. The guidelines then require an 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 worth noting that the GEA scheme does not consider geothermal energy associated with hydrocarbon developments as ‘EGS’, contrary to a definition by MIT (2006) during a national assessment of EGS potential in the USA. Also, direct uses of geothermal energy are clearly excluded from the GEA definitions.

In Europe, the Resource Assessment Protocol for GEOELEC (van Wees *et al.*, 2011) built on the work of Beardsmore *et al.* (2010), AGRCC (2010a and 2010b) and CGCC (2010), together with concepts from the oil and gas sector. It proposed to divide geothermal resources into three levels: level 1 for a pan-European prospective 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 state of divulgation in the public domain.

2. UNFC-2009 AND ITS APPLICABILITY TO RENEWABLE ENERGY SOURCES

The United National Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (‘UNFC-2009’) is a universally accepted and internationally applicable scheme for the classification and reporting of fossil energy and mineral reserves and resources. It 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 as shown in **Fig.6**.

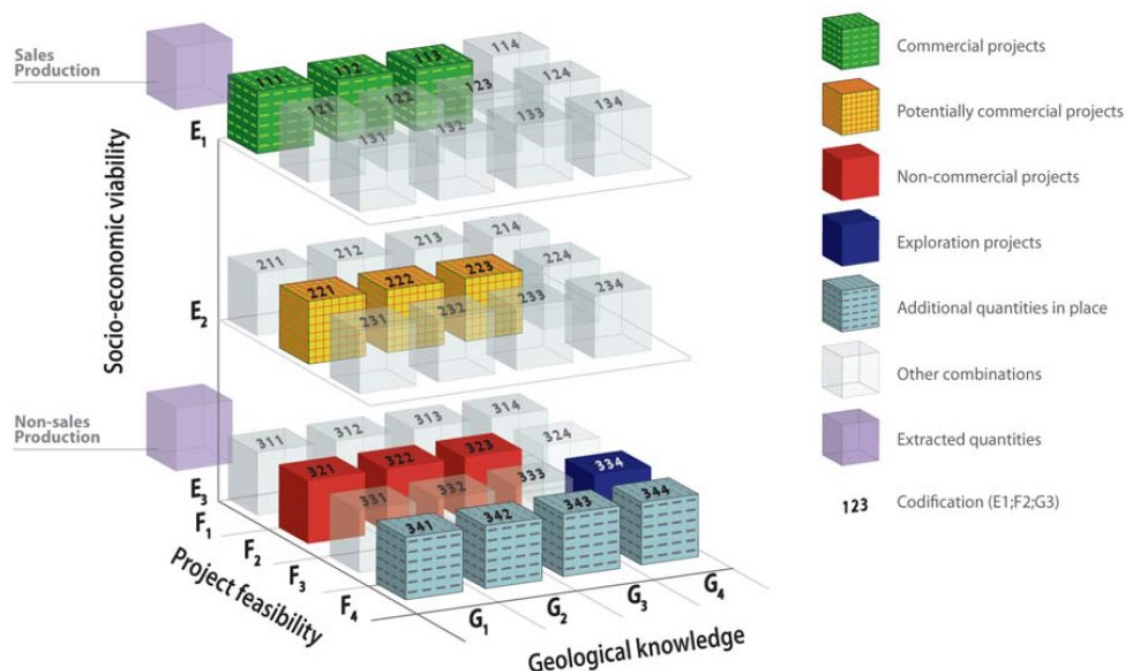


Figure 6: UNFC- 2009 categories and examples of classes (ECE, 2010).

The UNFC-2009 can already be used to normalize the classification of hydrocarbon and mineral resources. It also ensures alignment with widely used systems such as the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template and the Society of Petroleum Engineers (SPE)/World Petroleum Council (WPC)/American Association of Petroleum Geologists (AAPG)/Society of Petroleum Evaluation Engineers (SPEE) Petroleum Resource Management System (PRMS).

The CRIRSCO Template (CRIRSCO, 2013) provides a global framework and set of definitions for classifying estimates of solid mineral resources and reserves in the ground. Its scope states that, “The Template is applicable to all solid minerals, including diamonds, other gemstones, industrial minerals, stone and aggregates, and coal, for which Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves is required by the relevant regulatory authorities.” The CRIRSCO Template is only designed and intended to regulate the reporting of mineral resources and reserves that have already been confirmed to some extent by drilling. It allows the reporting of ‘exploration results’ prior to drilling, but forbids their description as ‘resources’ or ‘reserves’ at that stage. The CRIRSCO Template is not itself an enforceable document, but it forms the basis for legally enforceable mineral ‘reporting codes’ in many jurisdictions, including the JORC Code (Australasia), SAMREC Code (South Africa), Reporting Code (UK / Western Europe), CIM Guidelines (Canada), SME Guide (USA) and Certification Code (Chile).

The SPE PRMS (2007) provides global guidelines and standards for the estimation and reporting of liquid and gas hydrocarbon accumulations in the ground. It is designed for assessing and classifying petroleum resource and reserve estimates associated with specific commercial projects, rather than (for example) regional or global potential (except where derived from the sum of reported project potentials). From the Preamble to the PRMS: “A petroleum resources management system provides a consistent approach to estimating petroleum quantities, evaluating development projects, and presenting results within a comprehensive classification framework.” In doing so it ensures that resource estimates calculated and classified in different geographical regions by different individuals or groups are derived using the same sets of assumptions and procedures and are directly comparable. Compliance with the PRMS ensures transparent disclosure of the uncertainties associated with different petroleum resource estimates, and so provides investors with a consistent framework for assessing investment risk. For example, the PRMS allows the reporting of

estimates of prospective resources at an early stage of assessment, prior to any confirmation from drilling, but such estimates must be clearly identified as 'low confidence' or 'high risk'. While not technically enforced at a global level, a number of jurisdictions have enacted laws forcing petroleum exploration and production companies to report resources and reserves under the PRMS framework. For example, the ASX legally enforces petroleum companies listed on its bourses to comply with the PRMS.

The United Nations Economic Commission for Europe (UNECE 2012) called upon its Expert Group on Resource Classification (EGRC) to develop ideas on how the UNFC-2009 could apply to and integrate renewable energy resources. Following agreement at the fourth session of the UNECE EGRC held in Geneva, April 2013, a Task Force on the Application of UNFC-2009 to Renewable Energy Resources was established.

While renewable energy is defined as "energy that is derived from natural processes (e.g. sunlight and wind) that are replenished at a higher rate than they are consumed" (SE4ALL, 2013), the expectations of future cumulative energy production potential from such resources are bounded by the same or similar techno-economic and social constraints as those used to quantify fossil energy resources. Therefore, the future production potential from a renewable energy project can usefully be quantified using similar approaches as conventional resources, and the definitions and principles of the UNFC-2009 could also be applied to renewables.

For example, according to the Task Force on the Application of UNFC-2009 (2014), a renewable energy source is the equivalent of the terms 'deposit' or 'accumulation', which are used for fossil fuels and solid mineral resources. A renewable energy source is the primary energy (e.g. sun, wind, biomass, earth heat, river flow, tides, waves) available for extraction of (and conversion into) energy products. The main difference between renewable energy sources and fossil fuels or solid minerals is that, during the lifetime of the project, the renewable energy source is being replenished. A marketable energy product is directly linked to (or a direct replacement of) a fungible energy commodity and is saleable in an established market. Renewable energy resources are the cumulative quantities of extracted and marketable energy products from the renewable energy source, measured at the reference point.

At the fifth session of the UNECE EGRC (April 2014), the EGRC requested the Task Force to provide at least one draft renewable commodity-specific specifications for review at the sixth session.

To this end, the EGRC Task Force called upon the expertise of the International Geothermal Association (IGA) to provide the specifications for the application of UNFC-2009 to geothermal resources and reserves using the full granularity of UNFC-2009. The objectives of the IGA are to encourage research, the development and utilization of geothermal resources worldwide through the publication of scientific and technical information among geothermal specialists, the business community, governmental representatives, United Nations organizations, civil society and the general public. One of IGA's aims, as defined in the Charter of the Association, is to encourage, facilitate and, where appropriate, promote the coordination of activities related to worldwide research, development and application of geothermal resources. The UNECE EGRC and IGA agreed that their goals in the area of geothermal resources are mutually supportive and, in September 2014, IGA and the UNECE signed a Memorandum of Understanding (MoU) to develop a globally applicable harmonized standard for reporting geothermal resources. Such a standard will ensure greater consistency and transparency in financial reporting and enhance management of geothermal resources. Under this MoU, the IGA will work towards providing technology-specific rules ('specifications') for the application of the UNFC-2009 to geothermal resources. This work will be overseen by the UNECE EGRC. The geothermal specifications will provide the foundation and keystones for consistent application of UNFC-2009 for geothermal resources, and the meaningful comparison of geothermal resource estimates with other energy resources.

CONCLUSIONS

With no worldwide standards, guidelines or codes currently in existence, there is huge inconsistency in the manner that geothermal potential is estimated and reported. A common assessment and comparison framework would allow consistent reporting of renewable energy potential, including geothermal resources. The framework must be flexible enough to permit a comprehensive review of energy sustainability scenarios at project, company, national, or regional level. It must also be transparent so that investors, regulators, governments and consumers can be confident in their assessments of potential of renewable energy portfolios.

Many approaches have been proposed in the past for classifying geothermal potential: based on accessibility/discovery, or temperature/use/status, or by potential, or heat-in-place, or by electric power generation potential, or exergy or via geological confidence. However, each of these classification systems has drawbacks and limitations leaving the door open for ambiguity and subjectivity.

While it is acknowledged that developing a reporting system that can equally satisfy the requirements of different potential end users of the same geothermal resource, progress is being made in reconciling the specifics of geothermal resource classification with the definitions and principles of the UNFC-2009.

The universally accepted and applicable UNFC-2009 is a generic principle-based system that classifies resources using three criteria: economic and social viability, project status and feasibility, and geological knowledge. It can already be used to normalize the classification of hydrocarbon and mineral resources and a Task Force is currently investigating how UNFC-2009 can be applied to renewable energy resources. A working relationship has been established between the UNECE and the IGA to develop specifications and guidelines for the application of UNFC-2009 to geothermal energy and so allow the meaningful comparison of geothermal resource estimates with other energy resources.

REFERENCES

- AGRC - Australian Geothermal Reporting Code Committee (2010a): The Geothermal Reporting Code, Edition 2
- AGRC - Australian Geothermal Reporting Code Committee (2010b): Geothermal Lexicon for Resources and Reserves Definition and Reporting, Edition 2

- Baba A, Ozgener L, Hepbasli A. (2006): Environmental and exergetic aspects of geothermal energy. *Energy Sources*; 28(7):597–609
- Barbacki, A. (2012): Classification of geothermal resources in Poland by exergy analysis—Comparative study, *Renewable and Sustainable Energy Reviews* 16 (2012) 123– 128
- Beardsmore, G., Rybach, L., Blackwell, D. and Baron, C. (2010): A Protocol for Estimating and Mapping Global EGS Potential, Australian Geothermal Energy Conference
- Benderitter, Y. and Cormy, G.: Possible approach to geothermal research and relative cost estimate. In: Dickson MH and Fanelli M (eds), *Small geothermal resources*, UNITARRJNDP Centre for Small Energy Resources, Rome, Italy, (1990), 61-71.
- Bromley, C. (2009): Geothermal Resource Potential: categories and definitions, GIA-IGA Workshop, Madrid, 5-6 May
- CGCC - The Canadian Geothermal Code Committee (2010): The Canadian Geothermal Code for Public Reporting - Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves
- CRIRSCO (2013), International Reporting Template for the public reporting of Exploration Results, Mineral Resources and Mineral Reserves, http://www.criresco.com/templates/criresco_international_reporting_template_2013.pdf, downloaded on May 26, 2014
- ECE - ECONOMIC COMMISSION FOR EUROPE (2010): United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009, United Nations Publication, ECE Energy Series No.39, ISBN ISSN 1014-7225
- Etemoglu A.B. and Can M. (2007): Classification of geothermal resources in Turkey by exergy analysis. *Renewable and Sustainable Energy Reviews* 11(7): 1596-1606
- Falcone, G., Gnoni, A., Harrison, B., Alimonti, C. (2013): Classification and Reporting Requirements for Geothermal Resources, European Geothermal Congress 2013, Pisa, Italy, 3-7 June 2013
- GEA - Geothermal Energy Association (2010): New Geothermal Terms and Definitions - A Guide to Reporting Resource Development Progress and Results to the Geothermal Energy Association, November
- Goldstein, B.A., Hiriart, G., Tester, J., Bertani, R., Bromley, Gutierrez-Negrin, L.,C.J., Huenges, E., Ragnarsson, A., Mongillo, M.A. Muraoka, and V. I. Zui (2011): Great Expectations for Geothermal Energy to 2100, Proceedings, 36th Workshop on Geothermal Reservoir Engineering, Stanford, California, January 31 - February 2
- Hermann, W. A. (2006): Quantifying global exergy resources, *Energy* v. 31, p.1685-1702
- Hepbasli, A. (2008): A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future, *Renewable and Sustainable Energy Reviews* v. 12, p.593-661
- Hochstein, M.P.: Classification and assessment of geothermal resources. In: Dickson MH and Fanelli M (eds), *Small geothermal resources*, UNITAEWNDP Centre for Small Energy Resources, Rome, Italy, (1990), 31-59.
- Jalilinasrabad S. and Itoi R. (2012): Classification of Geothermal Energy Resources in Japan Applying Exergy Concept, *International Journal Energy Research*
- JORC - Australasian Joint Ore Reserves Committee (2012): The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves, 20 December 2012
- Lee, KC. (1996): Classification of geothermal resources, an engineering approach. Proceedings, 21st workshop on geothermal reservoir engineering, Stanford University
- Lee, K.C. (2001): Classification of geothermal resources by exergy, *Geothermics*, v.30, p.431-442
- Lovekin, J. (2004): Geothermal inventory, *Bulletin Geothermal Resources Council*, v.33, n.6, p.242-244
- MIT - Massachusetts Institute of Technology (2006): The Future of Geothermal Energy - Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. An assessment by an MIT-led interdisciplinary panel
- Muffler, L.P.J. (1979): Assessment of Geothermal Resources of the United States – 1978, U.S. Geological Survey Circular 790, 163p
- Muffler, P., and Cataldi, R. (1978): Methods for regional assessment of geothermal resources. *Geothermics*, Vol. 7, pp. 53-89, 1978
- Nathenson, M. (1975): Physical factors determining the fraction of stored energy recoverable from hydrothermal convection systems and conduction-dominated areas, U.S. Geological Survey, Open-file Report 75-525, 50p
- Ozgener L, Hepbasli A, Dincer I. (2004): Thermo-mechanical exergy analysis of Balçova geothermal district heating system in Izmir, Turkey. *ASME—J Energy Resour Technol*; 126:293–301
- Quijano, J. (2000): Exergy analysis for the Ahuachapán and Berlin geothermal fields, El Salvador. In: Proceedings of world geothermal congress, Kyushu-Tohoku, Japan, 28 May–10 June
- Ramajo, H., Tritlla, J., Levresse, G., Tello-Hinojosa, E., Ramírez, G. and Pérez, H. (2010): New SExI tools to evaluate the evolution and anthropic disturbance in geothermal fields: The case of Los Azufres geothermal field, México: *Revista Mexicana de Ciencias Geológicas*, v. 27, núm. 3, p.520-529
- Richards, M., Erdlac, R.J. Jr., Abbott, J. (2008): Geothermal Energy. In Texas Renewable Energy Resource Assessment - Report for the Texas State Energy Conservation Office, December

- Rybach, L. (2010): The Future of Geothermal Energy, Proceedings of World Geothermal Congress
- Rybach, L. (2013): Template for Global Geothermal Protocol, CanGEA 2013 Geothermal Conference, Calgary, 20-22 March
- SE4ALL - Sustainable Energy for All (2013), Renewable Energy, http://www.se4all.org/wp-content/uploads/2013/09/9-gtf_ch4.pdf, accessed on May 26, 2014
- SPE PRMS (2007): Society of Petroleum Engineers (SPE), American Association of Petroleum Geologists (AAPG), World Petroleum Council (WPC), Society of Petroleum Evaluation Engineers (SPEE). Petroleum Resources Management System, http://www.spe.org/industry/docs/Petroleum_Resources_Management_System_2007.pdf, downloaded on May 26, 2014
- Task Force on the Application of UNFC-2009 (2014), Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Renewable Energy Resources, Draft document prepared for circulation at the fifth session of the UNECE EGRC held in Geneva, 29 April-2 May 2014
- UNECE (2012): United Nations Economic Commission for Europe Energy industry calls for UNFC to embrace renewables, press release, 5 November
- Van Wees, J.D., Boxem, T., Calcagno, P., Lucasse, L. and Manzella, A. (2011): A Resource Assessment Protocol for GEOELEC, final draft, 6 December
- White, D.E. and Williams, D.L. (1975): Assessment of Geothermal Resources of the United States, U.S. Geological Survey Circular 726, 155 p
- Williams C.F., Reed M.J. and Anderson A.F. (2011): Updating the classification of geothermal resources. In: Proceedings of 26th workshop on geothermal reservoir engineering, Stanford University