



# Proposal of a consistent framework to integrate geothermal potential classification with energy extraction

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**Abstract.** The classification of geothermal resources is dependent on the estimate of their corresponding geothermal potential, so adopting a common assessment methodology would greatly benefit operators, investors, government regulators and consumers.

Several geothermal classification schemes have been proposed, but, to date, no universally recognised standard exists. This is due to the difficulty in standardising fundamentally different geothermal source and product types. The situation is not helped by the accepted use of inconsistent jargon among the geothermal community. In fact, the term “geothermal potential” is often interpreted differently by different geothermal practitioners.

This paper highlights the importance of integrating the classification of geothermal potential with that of geothermal energy extraction from well-defined development projects. A structured progression, from estimates of in situ quantities for a given prospect to actual production, is needed. Employing a unique, unambiguous framework would ensure that the same resource cannot exist simultaneously under different levels of maturity of the estimate (as in double bookings of resources), which would let stakeholders better assess the level of risk involved and the steps needed for a geothermal potential to achieve commercial extraction.

## 1 Introduction

There is a real challenge to reconcile nomenclature for in situ or in-place quantities of geothermal energy, potential (technical or economic or sustainable or developable), resources (inferred or indicated or measured) and reserves (probable or proven), to name but a few.

According to Rybach (2010), the theoretical potential describes the physically usable energy supply (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). The economic potential describes the time- and location-dependent fraction of the technical potential that can be economically utilised within the energy system under consideration. 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).

Often, the generic term “potential” is used in the public domain, without clear indication of what particular type of potential is being referred to (theoretical, technical, economic, sustainable or developable). Inevitably, this generates confusion among the stakeholders as to the actual expectations from a given geothermal prospect or development.

Classifying geothermal resources on the basis of the theoretical potential (or heat in place) leads to large figures that can be misleading and may be wrongly interpreted as recoverable energy. However, when the process to be implemented in order to recover a given resource is uncertain, the theoretical potential may represent the only estimate on hand.

Different methods are used to estimate geothermal potential, including power density (usually expressed in terms of  $\text{MW km}^{-2}$ ), stored heat (or volume method, independent of the method or rate of heat extraction) and numerical reservoir

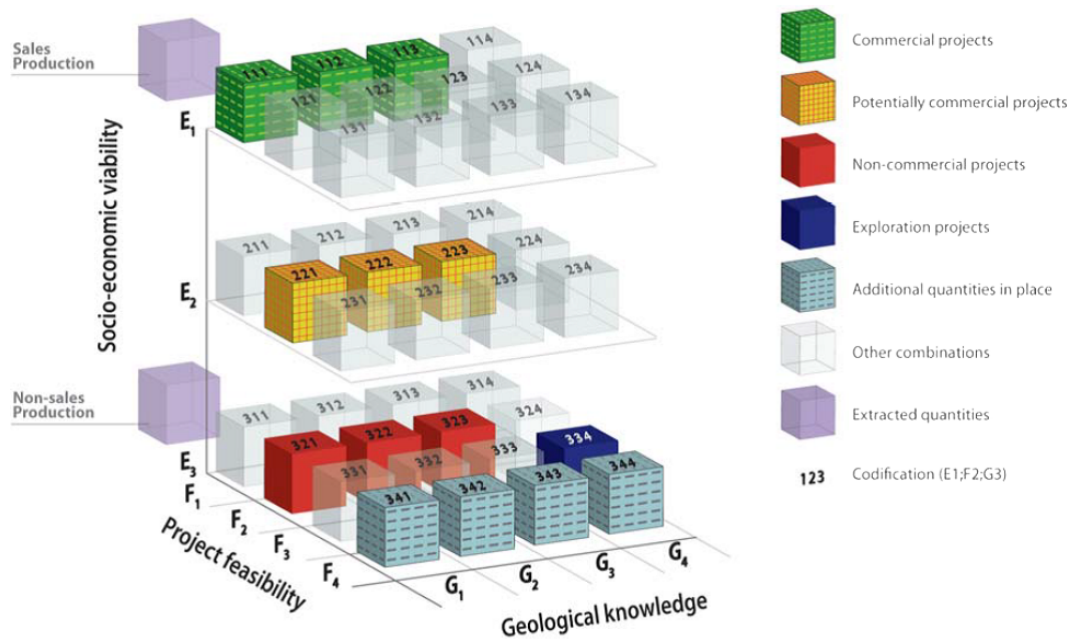


Figure 1. UNFC-2009 categories and examples of classes (ECE, 2013).

modelling (generally not suitable in the exploration and early development stage of a project). The resulting estimates carry different levels of confidence depending on whether they are based on indirect or direct evidence (e.g. geological studies and surface exploration vs. well logging and flow testing) and on the level of field maturity (exploration, appraisal or development). Inevitably, broad estimates of geothermal potential at country, continent or world scale rely on the assumption of parameters that are unknown.

Given the current global trend of increasing energy demand and the constant dilemma of whether renewable energy resources will be able to supplement or even replace conventional energy resources, it is crucial to assess future geothermal supplies at a large scale. This translates into a focus today on estimating and classifying geothermal theoretical potential, i.e. additional quantities in place that could be converted into actual production in the foreseeable future.

Unconventional, undiscovered and/or currently unrecoverable geothermal resources therefore need to be captured vis-à-vis the conventional, discovered and/or recoverable resources, in a consistent and structured way, so as to help stakeholders understand the level of risk involved and the steps needed for a geothermal potential to achieve commercial extraction.

## 2 The UNFC-2009

Several geothermal resources classification schemes have been proposed to date, yet no universally recognised standard exists. Falcone et al. (2013) provided a critical review

of key approaches proposed to date for geothermal resources classification.

The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) differs from other systems as it classifies estimated resource quantities using three axes: socio-economic variability ( $E$ ), project feasibility ( $F$ ) and geological knowledge ( $G$ ). The first set of categories (the  $E$  axis) designates the degree of favourability of social and economic conditions in establishing the commercial viability of the project, including consideration of market prices and relevant legal, regulatory, environmental and contractual conditions. The second set (the  $F$  axis) designates the maturity of studies and commitments necessary to implement mining plans or development projects. These extend from early exploration efforts before a deposit or accumulation has been confirmed to exist through to a project that is extracting and selling a commodity; they reflect standard value chain management principles. The third set of categories (the  $G$  axis) designates the level of confidence in the geological knowledge and potential recoverability of the quantities (ECE, 2013). Combinations of these criteria create a three-dimensional system as shown in Fig. 1.

The UNFC-2009 can already be used to normalise 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) International Reporting Template (IRT) and the Society of Petroleum Engineers (SPE)/World Petroleum Council (WPC)/American Association of Petroleum Geologists (AAPG)/Society of Petroleum

UNFC Classes Defined by Categories and Sub-categories						
Total Commodity Initially in Place	Extracted	Sales Production				
		Non-sales Production				
	Class	Sub-class	Categories			
			E	F	G	
Known Deposit	Commercial Projects	On Production	1	1.1	1, 2, 3	
		Approved for Development	1	1.2	1, 2, 3	
		Justified for Development	1	1.3	1, 2, 3	
	Potentially Commercial Projects	Development Pending	2 <sup>b</sup>	2.1	1, 2, 3	
		Development On Hold	2	2.2	1, 2, 3	
	Non-Commercial Projects	Development Unclassified	3.2	2.2	1, 2, 3	
		Development Not Viable	3.3	2.3	1, 2, 3	
	Additional Quantities in Place		3.3	4	1, 2, 3	
	Potential Deposit	Exploration Projects	[No sub-classes defined]	3.2	3	4
		Additional Quantities in Place		3.3	4	4

<sup>a</sup> Refer also to the notes for Figure 2.

<sup>b</sup> Development Pending Projects may satisfy the requirements for E1.

<sup>c</sup> Generic sub-classes have not been defined here, but it is noted that in petroleum the terms Prospect, Lead and Play are commonly adopted.

**Figure 2.** UNFC-2009 classes and sub-classes defined by sub-categories<sup>a</sup> (ECE, 2013). For the definition of categories and sub-categories and supporting explanations, see Annex I and Annex II of ECE (2013).

Evaluation Engineers (SPEE) Petroleum Resource Management System (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. The Task Force (2014) recently released specifications for the application to renewable energy resources for public comment. The aim is that of complementing these specifications with commodity-specific specifications for each type of renewable energy source, including geothermal.

In September 2014, the International Geothermal Association (IGA) and the UNECE signed a Memorandum of Understanding (MoU) to develop a globally applicable harmonised 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 guidelines

for consistent application of UNFC-2009 for geothermal resources, as well as a meaningful comparison of geothermal resource estimates with other energy resources.

Below there is a discussion on how UNFC-2009 could apply to geothermal energy resources, with a focus on the classification of potential future recovery by successful exploration activities and additional quantities in place associated with known and potential deposits, using the same framework that also allows classifying economic projects.

## 2.1 Potential vs. known deposit in UNFC-2009

With reference to Fig. 2, the UNFC-2009 allows differentiating between a known deposit and a potential deposit. A known deposit is a deposit that has been demonstrated to exist by direct evidence; a potential deposit is a deposit that has not yet been demonstrated to exist by direct evidence (e.g. drilling and/or sampling) but is assessed as potentially existing based primarily on indirect evidence (e.g. surface or airborne geophysical measurements) (ECE, 2013). Within UNFC-2009, the geologic uncertainty for discovered quantities is described using categories G1 to G3, while the geologic uncertainty for undiscovered quantities is described using category G4. Thus, a potential deposit includes quantities classified on the *G* axis as G4: “estimated quantities associated with a potential deposit, based primarily on indirect evidence” (ECE, 2013).

## 2.2 Additional quantities in place in UNFC-2009

With reference to Fig. 2, the UNFC-2009 allows reporting additional quantities in place as both quantities associated with a known deposit that will not be recovered by any currently defined development project or mining operation and quantities associated with a potential deposit that would not be expected to be recovered even if the deposit is confirmed (ECE, 2013). Additional quantities are classified on the *F* axis as F4 when “no development project or mining operation has been identified/in situ (in-place) quantities that will not be extracted by any currently defined development project or mining operation” (ECE, 2013). F4 means that no recovery factor is superimposed to estimates of in situ quantities. Additional quantities in place can be sub-classified as follows on the basis of the current state of technological developments (ECE, 2013):

- a. “F4.1: the technology necessary to recover some or all of these quantities is currently under active development, following successful pilot studies on other deposits, but has yet to be demonstrated to be technically feasible for the style and nature of deposit in which that commodity or product type is located;
- b. F4.2: the technology necessary to recover some or all of these quantities is currently being researched, but no successful pilot studies have yet been completed;

		Low Estimate	Best Estimate	High Estimate
Prospective Resources	Prospect	E3.2,F3.1,G4.1	E3.2,F3.1,G4.1+G4.2	E3.2,F3.1,G4.1+G4.2+G4.3
	Lead	E3.2,F3.2,G4.1	E3.2,F3.2,G4.1+G4.2	E3.2,F3.2,G4.1+G4.2+G4.3
	Play	E3.2,F3.3,G4.1	E3.2,F3.3,G4.1+G4.2	E3.2,F3.3,G4.1+G4.2+G4.3

**Figure 3.** Mapping of UNFC-2009 exploration projects to PRMS prospective resources (ECE, 2013). For the definitions of prospect, lead and play, see PRMS (SPE et al., 2007). For the definition of categories and sub-categories and supporting explanations, see Annex I and Annex II of ECE (2013). “Low”, “best” and “high” reflect the degree of uncertainty associated with the estimates. A low-estimate scenario is directly equivalent to a high confidence estimate, whereas a best-estimate scenario is equivalent to the combination of the high confidence and moderate confidence estimates. A high-estimate scenario is equivalent to the combination of high, moderate and low confidence estimates. Quantities may be estimated using deterministic or probabilistic methods.

- c. F4.3: the technology necessary to recover some or all of these quantities is not currently under research or development.”

### 2.3 Exploration projects in UNFC-2009

With reference to Fig. 2, in the UNFC-2009 exploration projects are classified on the *G* axis as G4 and on the *F* axis as F3: “feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data”, and “very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated” (ECE, 2013).

### 2.4 Combining *E*, *F* and *G* for exploration projects and additional quantities in place in UNFC-2009

Exploration projects and additional quantities in place are classified on the *E* axis as E3.

When combining the *E*, *F* and *G* categories, an exploration project in UNFC-2009 would fall under E3 F3 G4, and additional quantities in place would fall under E3 F4 G1, 2, 3 (for known deposits) or E3 F4 G4 (for unknown deposits). E3 implies “extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability” (ECE, 2013).

Considering that geothermal systems, like petroleum systems, deal with continuous fluid flow, the current bridging document between the PRMS (SPE et al., 2007) and UNFC-2009 could be used to map geothermal exploration projects and additional quantities in place to UNFC-2009.

		Low Estimate	Best Estimate	High Estimate
Unrecoverable	Discovered	E3.3,F4,G1	E3.3,F4,G1+G2	E3.3,F4,G1+G2+G3
	Undiscovered	E3.3,F4,G4.1	E3.3,F4,G4.1+G4.2	E3.3,F4,G4.1+G4.2+G4.3

**Figure 4.** Mapping of UNFC-2009 additional quantities in place to PRMS unrecoverable quantities (ECE, 2013). “Unrecoverable” implies that the technology has not been demonstrated to be commercially viable and is not currently under active development, and/or there is not yet any direct evidence to indicate that it may reasonably be expected to be available for commercial application within 5 years. For the definition of categories and sub-categories and supporting explanations, see Annex I and Annex II of ECE (2013). “Low”, “best” and “high” reflect the degree of uncertainty associated with the estimates. A low-estimate scenario is directly equivalent to a high confidence estimate, whereas a best-estimate scenario is equivalent to the combination of the high confidence and moderate confidence estimates. A high-estimate scenario is equivalent to the combination of high, moderate and low confidence estimates. Quantities may be estimated using deterministic or probabilistic methods.

There are four cells within the *E–F* matrix that map directly and uniquely to corresponding PRMS project maturity classes; these cells relate to exploration projects (prospective resources in PRMS) and additional quantities in place (unrecoverable in PRMS) (ECE, 2013). Accordingly, geothermal exploration projects could be further defined via sub-categories as E3.2 F3.1,2,3 G4, where the F3 sub-categories allow specifying the level of maturity of the project (Fig. 3). Similarly, additional quantities in place could be defined as E3.3 F4.1, 2, 3 G4 (Fig. 4), with the F4 sub-categories indicating the current state of technological developments.

E3.2 indicates that “economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase)” (ECE, 2013), while E3.3 suggests that, “on the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future” (ECE, 2013).

Considering that, for recoverable estimates of energy resources that are extracted as fluids, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation, recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorised on the basis of three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3 (ECE, 2013). G1, G1+G2 and G1+G2+G3 represent single specific scenarios that are representative of the extent of the range of uncertainty of the recoverable/potentially recoverable quantities and they correspond to low estimates (high confidence),

best estimates (high and moderate confidence) and high estimates (high, moderate and low confidence), respectively.

### 3 Conclusions

The threefold UNFC-2009 framework allows one to capture the nuances of each geothermal quantity, from in situ potential to confirmed economic production. Its flexibility and granularity permits the classification of quantities that have been estimated primarily on the basis of indirect evidence (e.g. country-based resource mapping studies), as well as quantities at a more specific project level.

UNFC-2009 deliberately avoids the use of ambiguous jargon, having benefited from valuable lessons learnt from the fossil fuels and solid mineral sectors. Nevertheless, the development of dedicated geothermal specifications is needed to make UNFC-2009 fully functional for geothermal resources classification, as it was originally developed for non-renewable energy.

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