Regional and country-level assessments of geothermal energy potential based on UNFC principles

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Keywords: global resource assessment, country-level resource assessment, aggregation of quantities, UNFC

ABSTRACT

The United Nations Framework Classification for Resources (UNFC) is a universally acceptable and internationally applicable scheme for the sustainable management of all energy, mineral and anthropogenic resources. As of 2016, the UNFC is also applicable to geothermal energy resources.

Prescribing quantification methods for resource estimates goes beyond the scope of the UNFC, as multiple best practices, as well as analytical and numerical tools already exist, which encompass the significantly wide range of geothermal geological settings, heat recovery and conversion technologies and socio-environmental contexts. Nevertheless, the Project concept embedded in the UNFC, together with the need to define the associated level of confidence in the potential recoverability of the quantities, requires users to link different types of geothermal resources with corresponding viable project development schemes. This facilitates the choice of suitable quantification methods (probabilistic, scenario or incremental), compatible with the UNFC classification principles, which is particularly relevant to regional and country-level assessments of undeveloped geothermal potential.

This paper critically reviews recently published country and global geothermal resource assessments, based on different, non-UNFC methods and presents a high-level superposition of the published assessments with the unique features of the UNFC.

1. INTRODUCTION

The UNFC (ECE, 2013) is a universally acceptable and internationally applicable scheme for the sustainable management of all energy and mineral resources. Under the UNFC, quantities are classified by three fundamental sets of categories, as shown in Fig.1.

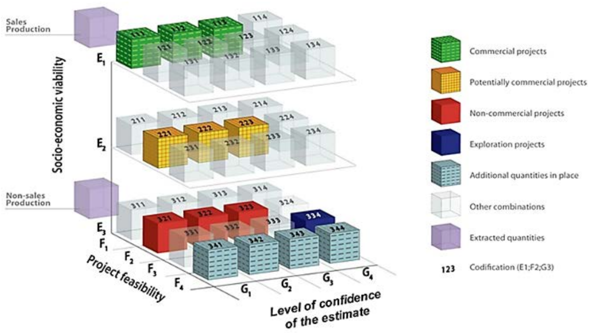

Figure 1: UNFC categories and examples of classes (ECE, 2013).

The UNFC has a key role to play in the development of global energy scenarios, thanks also to its synergies with the Pathways to Sustainable Energy Project of the United Nations Economic Commission for Europe (UNECE, 2019).

Following the development of the umbrella specifications for the application of the UNFC to renewable energy resources (Denelle et al., 2016), a dedicated set of geothermal specifications was issued, followed by complementing case studies (Falcone et al., 2016, 2017).

The global uptake of the UNFC for application to geothermal resources is confirmed by the numerous case studies published and presented internationally, e.g. at the annual meeting of the UNECE's Expert Group on Resource Management in Geneva and at the European Geothermal Congress. In 2018 and 2019, the International Geothermal Association (IGA), International Renewable Energy Agency (IRENA) and the Energy Sector Management Assistance Program of the World Bank Group (ESMAP), with the support of the UNECE, jointly ran a program of workshops and implementation trials across three countries (Indonesia, St. Lucia and Ethiopia) to train local geothermal professionals on how to use UNFC to classify geothermal energy resource estimates for portfolios of real-world geothermal projects. The lessons learnt from this in-country training, dissemination and implementation programme will be reported at the World Geothermal Congress 2020.

In what follows, a critical discussion on the importance of Project definition will be presented, with a focus on notional Projects for the assessment of undeveloped resources within low-resolution studies (e.g. regional and country-level assessments).

2. THE UNFC PROJECT DEFINITION

The UNFC was designed as a Project-based system for the evaluation and classification of fossil energy and mineral reserves and resources located on or below the Earth's surface. Further development has demonstrated that the system can also be applied to all energy and mineral resources. In the UNFC, '*A Project is a defined development or mining operation which provides the basis for economic evaluation and decision-making. In the early stages of evaluation, including exploration, the Project might be defined only in conceptual terms, whereas more mature Projects will be defined in significant detail*' (ECE, 2013).

The level of detail with which a Project is defined depends on its maturity. The activity or set of activities which constitute the defined Project include consideration of the development scheme that could or will be implemented, or has been implemented.

Although defining a Project at an early stage of evaluation is challenging, no estimate of potentially recoverable quantities can be made without it. As reported in Falcone et al. (2016), '*The creation of notional or hypothetical 'standard' projects (with associated reference point) may allow an estimate and classification of all the nation's Geothermal Energy Resources, including those not yet linked to defined projects*'. Too often are regional and country geothermal resource assessments reported without implementation of the Project concept, resulting in misleading (overestimated) theoretical potentials.

3. TOP-DOWN AND BOTTOM-UP ASSESSMENTS

Historically, regional and country-wide assessments have started as a high level, top-down approach, applying harsh averaging of key parameters across considerably vast geographical areas and taking a low-resolution approach, e.g. ignoring land accessibility, socio-economic-environmental aspects and end-users' demand. A worldwide example of this practice is given by Limberger et al. (2018who present a global assessment of geothermal energy resources within deep aquifers for direct use. A more rigorous approach to assessing areal extent, gross thickness and depth of aquifers is given by ThermoGIS (2019), which benefited from having access to more and better-quality input and calibration data.

A recent example of country-wide assessment is given by Busby and Terrington (2017), which focuses on the engineered geothermal system resource base that might be available for the generation of electricity in Great Britain.

Neither Limberger et al. nor Busby and Terrington try to superimpose a realistic, though notional, Project concept. The application of one average recovery factor at regional level neglects the fact that only a limited number of doublets can be developed and sustained within a total potential area, for example; this would be analogous to the concept of drainage area for hydrocarbon developments.

An analogue to accounting for land accessibility for geothermal development is offered by the potential exploitation of shale gas resources. As reported by Harrison et al. (2019), operating in a densely populated region of England, with major traffic congestion, in close proximity to national parks, and ever-increasing demands on land use, will continue to pose difficulties. Taylor et al (2013) estimated that a single well pad in the area, hosting 10 horizontal wells, would require 11 trucks accessing the site every day for the first 2 years of drilling and completion activity. Such concerns have led to studies by Clancy et al (2017), which estimated the likely physical footprint of well pads if shale gas developments were to proceed in the UK, and their impact upon buildings and roads, the carrying capacity of the environment, and how resource recovery may be limited. The study showed that when surface and subsurface footprints were considered, the mean carrying capacity within the licensed blocks was 26%, which would impact on the potential recovery of shale gas resources.

Even when a notional Project concept is superimposed to regional area estimates, caution should be applied in assuming when the resources could become available. It is highly unrealistic that all the geothermal 'potential' of a given region, or country (or of the world) could be unlocked at the same time, due to difference in Projects' maturity, i.e. the maturity of studies and commitments necessary to implement a Project.

Modelling sustainable energy scenarios involves the fundamental challenge of simultaneously and coherently accounting for energy stocks availability, technology readiness, environmental and social implications (beyond climate change), policies, access to distribution networks, GDP, population growth and full life cycle assessment of energy extraction and conversion infrastructure. The overall maturity or readiness of a Project cannot be disjointed from subsurface, technological and socio-economic environmental aspects, contrary to what is discussed by Young and Levine (2018) and assumed in the GeoRePORT Input Spreadsheet (NREL, 2017), where the Project Readiness Levels triangle is generated based on user-defined qualifying criteria that are not linked to other tabs in the spreadsheet.

3.1 Aggregation of quantities

In the UNFC, a bottom-up resource assessment approach requires the aggregation of estimated quantities associated with development projects that are classified in the same categories. According to Falcone et al. (2016), '*For national resource reporting, the* *aggregation of known projects from commercial, non-commercial and/or governmental organizations may not cover the total national Geothermal Energy Resources. The creation of notional or hypothetical 'standard' projects (with associated reference point) may allow an estimate and classification of all the nation's Geothermal Energy Resources, including those not yet linked to defined projects*.' An example of a nationwide geothermal resource assessment for UNFC classification is given by Case Study 5, Dutch Rotliegend Play area – Nationwide, which was led by Mijnlieff in Falcone et al. (2017).

When aggregating the reserves or resources of a company, two common practices exist in the oil and gas sector (Falcone et al., 2007). The first is based on the arithmetic summation of deterministic estimates, whilst the second performs a probabilistic (or statistical) aggregation of probabilistic distributions. To correctly add together the ranges of estimated recoverable quantities from a number of fields, the second method of probabilistic aggregation must be used. Resources distributions, which tend to be lognormal as they are based on permeability variations, are characterised by having one of their tails being longer than the other in the positive direction. The only point where the deterministic and probabilistic results coincide is at the mean or average value of the aggregated distribution. Thus, when working out the overall resources distribution curve of several fields, the median or P50 of the total curve does not correspond to the sum of the individual P50s. The positively skewed lognormal distribution ensures that the computed mean is always higher than the P50 value. The larger the positive skew of the resultant resources distribution, the bigger the difference between the computed mean and the P50 value.

A top-down and a bottom up approach to assessing geothermal energy resources in a given region or country, or in the world should converge to the same answer, that being a full range of possible outcomes reflecting the level of confidence in the potential recoverability of the quantities, i.e. all significant uncertainties impacting the estimated resources quantities that are forecast to be extracted by the ensemble of Projects within the same maturity category. See Figs 2-3.

While different best practices exist to estimate geothermal energy resources at field/Project level with associated uncertainty analysis, including experimental design (ED) techniques inherited from the oil and gas sector (see Fig. 4) (Quinao and Zarrouq, 2018), less is done at regional and country level to systematically capture the spread in estimates of the recoverable quantities.

G-axis	Designates the level of confidence in the potential recoverability of the quantities related to e.g. geological knowledge
Category	**Definition**
G1	Quantities associated with a *known deposit* that can be estimated with a **high level of confidence**.
G2	Quantities associated with a *known deposit* that can be estimated with a **moderate level of confidence**.
G3	Quantities associated with a *known deposit* that can be estimated with a **low level of confidence**.
G4	(Best) Estimated quantities associated with a *potential deposit*, based primarily on indirect evidence.

Figure 2: UNFC categories representing the level of confidence in the potential recoverability of the estimated quantities.

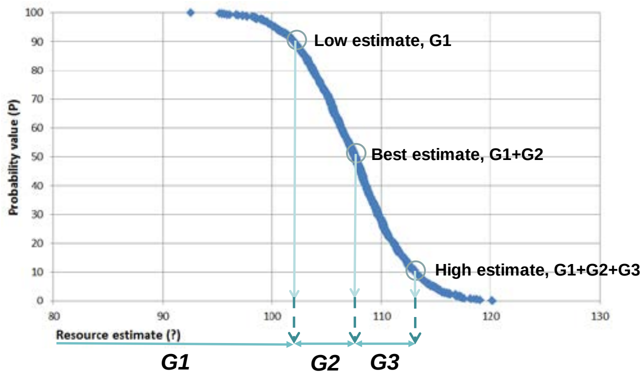

Figure 3: UNFC, G-axis: spread of probabilistic estimate.

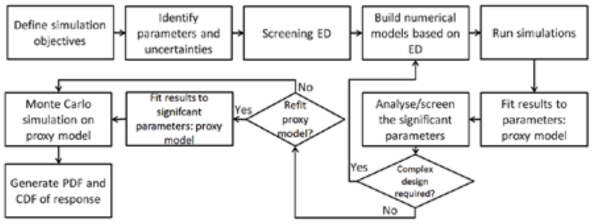

Figure 4: Experimental Design and Response Surface Methods (ED and RSM) workflow for probabilistic resource assessment using numerical models (Quinao and Zarrouq, 2018).

4. CONCLUSIONS

Practices such us the flat use of average recovery factors or cut-off values without accounting for different notional Projects within the same area, land accessibility and other key feasibility factors can lead to potentially unrealistic results. Some approaches neglect the fundamental principle of aggregation of quantities, while others pose a discontinuity between Project readiness and independently-generated geological, technical and socio-economic attributes.

While the UNFC, as a classification framework, does not prescribe quantification methods for resource estimates, it encompasses the Project, together with the need to define the associated level of confidence in the potential recoverability of the quantities. This facilitates the choice of suitable quantification methods (probabilistic, scenario or incremental), compatible with the UNFC classification principles, which is particularly relevant to regional and country-level assessments of undeveloped geothermal potential.

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