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8 Years on: Incremental Impact of Worldwide Implementation of the United Nations Framework Classification for Geothermal Energy Resources

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ABSTRACT

From the original publication of the specifications for the application of the United Nations Classification Framework (UNFC) to geothermal energy resources, followed by the October 2022 release of the supplementary specifications, this paper presents case studies that confirm the significant level of global uptake to date. The experience so far shows the importance of taking an international and multi-stakeholder approach, as well as embracing the full spectrum of geothermal energy applications. With organizations such as the International Geothermal Association, the International Renewable Energy Agency, the World Bank Energy Sector Management Assistance Program, Geothermal Rising, the US Department of Energy, the Geothermal Energy Association, the International Energy Agency Geothermal Implementing Agreement and the European Geothermal Energy Council having supported various stages of development and implementation of UNFC for geothermal energy resources, the outlook points to further positive impact.

1. INTRODUCTION

As highlighted in the recent report on the future of geothermal energy (IEA, 2024), geothermal is a versatile, clean and secure energy source. The potential for geothermal is now truly global and investment is growing. In 2023, geothermal energy use reached 5 exajoule (EJ), accounting for almost 0.8 % of global energy demand, but it remains the second least-used clean energy source after ocean energy (**Figure 1**).

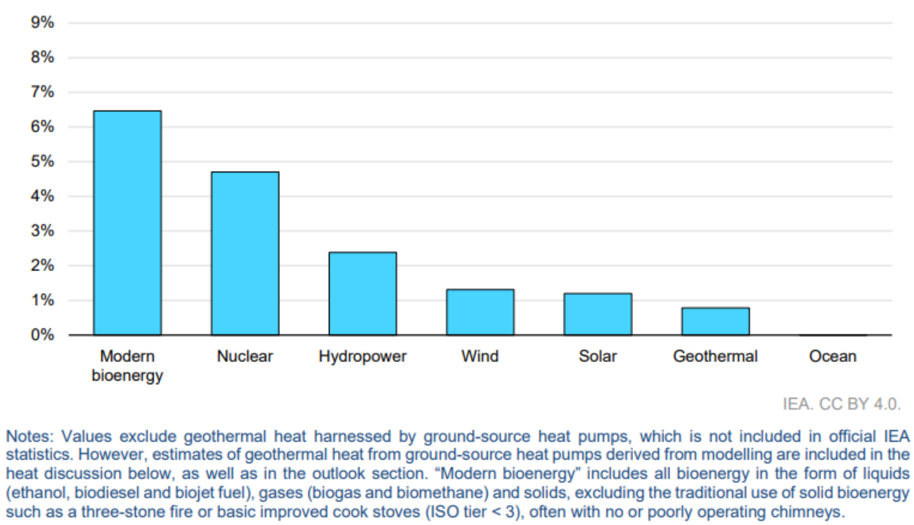


Figure 1: Shares of clean energy technologies in total energy demand, 2023 (IEA, 2024).

A common assessment framework for geothermal energy resources is needed by investors, regulators, insurers, 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, and to offer greater confidence in development. The United Nations Framework Classification (UNFC) is a universal system for classifying and reporting minerals, energy, and other resources. It provides a standardized approach to ensure consistency, transparency, and sustainability in resource management. By integrating environmental, social, and economic considerations, UNFC aligns with global sustainability goals, including the 2030 Agenda for Sustainable Development and the Paris Agreement. Its comprehensive framework supports decision-making processes across various sectors, facilitating efficient and responsible resource use globally. UNFC is essential for governments, industries, and stakeholders committed to sustainable resource management.

UNFC has seen significant global uptake as a standardized system for classifying and managing resources across sectors. It has been mandated under the European Union's Critical Raw Materials Act (EU CRMA) for monitoring and classifying strategic projects. In Africa, UNFC forms the basis of the African Mineral and Energy Resource Classification (AMREC), endorsed under the African Mining Vision (AMV), with the Pan-African Resource Reporting Code (PARC) aligning public reporting to UNFC standards, including for geothermal resources. UNFC has been recommended for widespread adoption in the Asia-Pacific region through ESCAP's Ministerial Declarations on Sustainable Resource Management. The UN Regional Economic Commissions (UN RECs) are collaborating with the United Nations Economic Commission for Europe (UNECE) to implement UNFC across all regions, supporting its integration into national resource governance frameworks. UNFC applies to various resources, including minerals, petroleum, renewable energy, nuclear fuel, injection projects for geological storage, and anthropogenic resources. UNFC is developed and maintained by the UNECE Expert Group on Resource Management (EGRM), with the support of various stakeholders from governments, industry, academia and civil society. Specifically in the area of renewable energy, ad hoc specifications already exist for geothermal, bioenergy, solar and wind energy resources, reinforcing its role in sustainable resource management worldwide. No other system exists that encompasses such scope.

In 2014, UNECE called upon the expertise of the International Geothermal Association (IGA) to provide specifications for the application of UNFC to geothermal resources. UNECE and IGA agreed that their goals in the area of geothermal resources were mutually supportive and signed a Memorandum of Understanding (MoU) to develop a globally applicable harmonized standard for reporting geothermal resources. The specifications for the application of UNFC to geothermal energy resources first became operational on 30 September 2016 (Falcone *et al*., 2016). They were originally developed by a working group of expert volunteers. Face-to-face meetings of the working group by means of periodic workshops were made possible by the support of the Energy Sector Management Assistance Program of the World Bank Group (ESMAP), the United States Department of Energy (DOE), and the Geothermal Resources Council (GRC, now Geothermal Rising), with the logistical organization of the IGA Service Company. In addition, the IGA Resources and Reserves Committee, the former Geothermal Energy Association (GEA) and the International Energy Agency Geothermal Implementing Agreement (IEA-GIA) reviewed an advanced draft of the specifications before their public release. Additional technical input was provided by the UNECE EGRM task force on renewable energy and the EGRM technical advisory group. In 2017, 14 geothermal case studies were published. On 25 October 2022, an update was issued in the form of supplementary specifications (Falcone *et al*., 2022). Their development was undertaken by the IGA UNFC Ad Hoc Committee of expert volunteers, with reviews and additional technical input by the EGRM renewable energy working group, the EGRM technical advisory group and expert individuals.

2. WORLDWIDE IMPLEMENTATION OF UNFC FOR GEOTHERMAL ENERGY RESOURCES

In what follows, selected case studies are presented of global dissemination and implementation of the UNFC geothermal specifications to date.

2.1 Pilot applications in the Caribbean, Ethiopia and Indonesia

In 2018 and 2019, the IGA, International Renewable Energy Agency (IRENA) and ESMAP, with the support of UNECE, jointly ran a program of workshops and implementation trials across three regions to train local geothermal professionals on how to use UNFC to classify geothermal energy resource estimates for portfolios of real-world geothermal projects. The key outcomes from that program were reported by Beardsmore *et al.* (2021) and IRENA and IGA (2021). These included an assessment of the level of effort required to train professionals with no previous experience of applying UNFC; identification of fundamental UNFC concepts that required the most explanation and translation for geothermal professionals (for example, definitions of 'project' and 'geothermal energy resource'); observations of the key data requirements to allow project classification (for example, status of the license to operate, maturity of subsurface and engineering studies, and availability of an energy production profile for the project lifetime). Additionally, the program led to an appreciation for the interdisciplinary human effort required to rigorously classify and report geothermal energy resources; identification of different perspectives that different stakeholders bring to the classification process; development of an understanding of where additional written aids (for example, worksheets and checklists) and guidelines could assist geothermal professionals to apply UNFC; and an appreciation of the value of joint IGA-IRENA-ESMAP-UNECE programs of this nature to incentivize the uptake of renewable energy.

The Indonesian workshop was made possible through the financial assistance of ESMAP and IGA, with additional help from IRENA, UNECE, Jacobs (funded by the Government of New Zealand 'GEOINZ' program), Badan Geologi and the Institute of Technology Bandung (ITB). The success of the East Caribbean workshop was due to financial support from IRENA, with logistical and other support from the Organization of the Eastern Caribbean States (OECS) Commission, UNECE, IGA and ESMAP. The Ethiopian workshop was only possible due to financial support from IRENA, a venue provided by ESMAP, and other assistance by UNECE, IGA and the African Geothermal Center of Excellence (AGCE). IGA trainers donated their time to participate in each of the training workshops and to provide follow-up support to complete classification statements for each region.

2.2 Australia

The application of UNFC reached a new milestone in 2022 when the Government of Queensland, Australia, updated the state's regulations regarding geothermal energy resources. Queensland's Geothermal Energy Regulation 2022 (Queensland Government, 2022) explicitly legislates that geothermal exploration and production license holders must comply with the UNFC geothermal specifications when classifying and reporting geothermal energy resources to the government. The new regulations were approved by the Governor-in-Council in Brisbane and came into effect on 1 September 2022.

As of 2 February 2023, the Australian Geothermal Association (AGA, 2023) endorses UNFC for geothermal resource reporting, notably no longer supporting the previous Australian Geothermal Reporting Code (2010). AGA has also made submissions to the Government of

Western Australia to legislate compliance with UNFC for geothermal energy reporting. The government has responded favorably to the concept but has deferred implementing any changes until the Petroleum and Geothermal Energy Resources Act (1967) is next amended at some indefinite future time.

Beardsmore (2024) adopted the terminology of UNFC when describing hot sedimentary aquifer geothermal energy sources and resources in Australia. Specifically, the terms ‘source’, ‘resource’, ‘known’ and ‘potential’ were used in their UNFC context throughout the paper.

2.3 New Zealand

The Waikato Regional Council, which regulates the majority of high temperature geothermal systems in New Zealand, has run a trial application of UNFC classification to understand the resource available in their Region and is in the process of considering mandating regular UNFC reporting on projects that have Resource Consents (project already approved for development). They have trained their key technical consultant reviewers in UNFC in order to be able to review assessments made by developers / operators. Jacobs has published a comprehensive report applying UNFC for an inventory of geothermal projects in the Waikato Region in New Zealand. The progress with this initiative was reported in Think GeoEnergy (Cariaga, 2023). This assessment covered both electricity and heat production projects and potential.

The results from the Waikato Region were summarized in terms of the UNFC broad classifications of viable, potentially viable, non-viable and prospective projects and highlighted that, while the region has a substantial installed capacity and there have been recent new projects and expansions, there is a large gap in terms of any future prospects that have been tested by drilling and ready to develop (Ussher *et al*., 2023). UNFC’s focus on project maturity has proven to be highly valuable in having a view of the future pipeline of development, which was not apparent in prior approaches such as the Australian Geothermal Reporting Code. The assessment was updated in 2024 and after just one year there was a notable change in the maturity and classification of several projects, reflecting the value of regular updating of portfolios of projects. This also demonstrated that the UNFC system has useful granularity that is sensitive to the annual changes experienced in project development, especially as projects near construction. The application of UNFC to the geothermal inventory of the Waikato Region has therefore proven highly successful, providing a concise compilation of all projects on a common assessment basis. Geothermal operators were actively engaged in the process, displaying a high level of interest and cooperation and the use of standardized templates facilitated efficient compilation of UNFC reports.

Project Class	PJ (e)		
	G1	G2	G3
Viable Projects	269.9	43.0	32.3
Potentially Viable Projects	24.4	10.4	5.8
Non-Viable Projects	10.0	5.0	5.0
	G4.1	G4.2	G4.3
Prospective Projects	147.0	57.0	80.0
Total	478.3	115.4	123.1

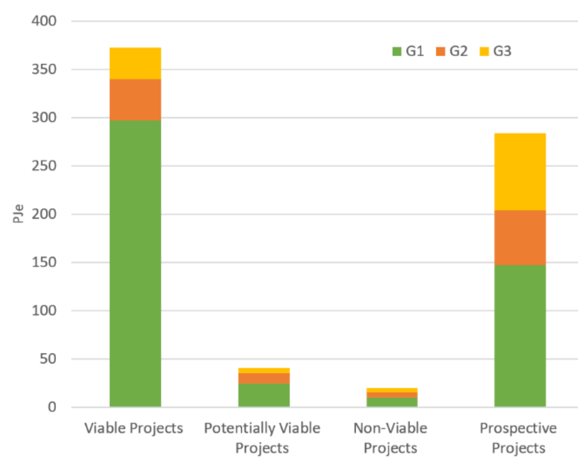


Figure 2: Example output from the Waikato Region UNFC inventory in 2023, showing the consolidation using standard UNFC categories, which provides a useful view of the geothermal pipeline (Ussher *et al.*, 2023).

A recent report, published by Bromley *et al.* (2024) details a superhot / supercritical geothermal inventory and an assessment based on the updated UNFC geothermal specifications by Falcone *et al.* (2022). The UNFC methodology categorises the New Zealand inventory of superhot geothermal projects at E3.2, F4.2, G4.1 (344), reflecting the current level of environmental-economic-social viability, technical feasibility, and level of confidence. The team developed an assessment methodology to determine the resource potential. The inventory uses geophysical data and interpretations, primarily magnetotellurics, available in the Taupō Volcanic Zone, in the Waikato and Bay of Plenty Regions, along with the Northland Region (Ngawha). It considers the depth range of 3.5 to 6km only; this depth targets the ‘deep roots’ of subcritical geothermal systems where the temperatures are >400°C. Because of limited geophysical data coverage of the areas included, and constraining the lower depth limit at 6km, the inventory likely underestimates the nation’s potential. Removing the areas that are protected by regulatory planning provisions, the inventory identifies a total capacity of about 3.5 GWe, 30 TWh / year of electricity. The assessment assumes a project lifetime of 35 years, which is the maximum consent duration that can be granted under the Resource Management Act (1991); if the heat source is not yet depleted at the completion of a nominal project lifetime, a new project can be defined at the same site.

An introduction to UNFC has been included within the curriculum for the Geothermal Project Management short course that is run by the University of Auckland in collaboration with industry partners (O’Sullivan, 2023). The approximate 150 attendees for this series of courses over several years from Indonesia, the Philippines and Africa who are typically emerging technical managers from private companies, state owned developers and energy regulators, have shown considerable interest in UNFC and even made effort to promote in their home regions (for example Nyange, 2024).

2.4 Central American Integration System (SICA)

Since 2020, different efforts have been made to introduce UNFC for geothermal development in the SICA region via the Geoscience Technical Group (GTG), supported by the German Cooperation Project Yacimientos. The translating of the original UNFC geothermal specifications into Spanish represented an important step to facilitate training in the region. A first training was delivered by IGA in 2020 and was used to introduce the topic to the region. The training led to sample applications in Costa Rica and El Salvador, and served as a basis to recommend UNFC to the region. Based on these efforts, in July 2023, SICA's Energy Ministers Council ('Consejo de Ministros de Energía del SICA') instructed the application of UNFC in the region. A second training was then developed by geothermal expert members of GTG to facilitate the implementation of the instruction. The workshop, lead by El Salvador and Costa Rica, was held in October 2023, where direct use projects in the region were classified using UNFC; also, a digital tool to create classification reports, developed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) was introduced. A workshop report was produced and published (GTG, 2024), with a planned English translation. The positive experiences in El Salvador and Costa Rica were later presented at the 2nd Workshop on Geothermal Energy in Latin America in Costa Rica, organized by the European Association of Geoscientists and Engineers (EAGE) in November 2023.

Based on the engagement of GTG, assessment of different projects in Central America was possible, as well as participation of more regional stakeholders in the efforts to put UNFC into practice in the regional geothermal sector. Experience in El Salvador showed the benefits of using UNFC to track project maturity over time, starting from non-mature projects. Experience in Costa Rica and Honduras demonstrated the applicability of UNFC to direct use projects (hot springs and cascaded applications).

To ensure continued participation of the SICA region in facilitating the application of UNFC to geothermal resources, Eddy Sánchez Rivera (Instituto Costarricense de Electricidad) is currently a member of the EGRM's UNFC adoption group, representing GTG.

2.5 Africa

In addition to the pilot in Ethiopia discussed in Section 2.1, some limited training in UNFC was provided to the Ethiopian geothermal energy regulator within the Ministry of Mines in 2024 as part of a New Zealand Aid Program.

A long-term initiative to ensure that Africa's mineral and energy resources are managed sustainably and will equitably contribute to its socio-economic transformation has led to a high-level African Mining Vision (AMV). That self-determined vision has in turn led to the development of the African Mineral and Energy Resources Classification and Management System (AMREC) and the Pan-African Resource Code (PARC) under coordination of the African Union - African Minerals Development Centre (AMDC, 2024). These are pioneering frameworks designed to align Africa's resource management with global standards and are explicitly built on the foundations of UNFC and the United Nations Resource Management System (UNRMS). PARC explicitly includes the UNFC classification framework, and provides for the application to minerals, petroleum and renewable energy projects including specific reference for geothermal.

The final adoption of the AMREC/PARC policy document was concluded in the declaration and approval by the 40th Ordinary Session of African Heads of States of the African Union on 5th February 2022. This means that there is now pan-African acceptance at political level of AMREC-PARC with its UNFC basis, including the application to geothermal energy resources. Nations can now adopt AMREC-PARC or UNFC and require developers or regulators to use these standards as each nation sees fit. This overarching acceptance of UNFC by Africa is a significant step forward in global adoption of UNFC and reflects the region's self-determination to adopt and build on an international standard that suits their needs in preference to any alternatives that may be narrower industry-based systems for reporting particular resource types.

In support of wider promotion of UNFC application for geothermal in Africa, the New Zealand Ministry of Foreign Affairs and Trade funded a 2-day pre-conference training and workshop at the ARGEO-C10 conference held in Dar Es Salaam, Tanzania in 2024. This workshop was led by consultant Jacobs (who have been delivering aspects of New Zealand's assistance in the region) to 16 people from across the East Africa region. In this workshop, a simplified approach for classifying projects was tested and successfully applied. This also tested an approach that extended standard UNFC maturity Categories to include more granularity for prospective projects that are still being explored before any deep drilling. The outcome was that the trainees, working in small groups, quite effectively managed to classify all known geothermal projects in Africa with reasonable accuracy within a day's work. The results of this were presented to the technical sessions of the ARGEO-C10 conference. Similar to the New Zealand case, this regional compilation highlighted the shortfall of projects that have been successfully drilled and ready to develop, meaning a lot more exploration drilling is needed before substantially more new generation projects can be expected in the region. This again highlights the value of UNFC and its project-oriented maturity assessment approach. This exercise also reveals that UNFC can be "demystified" and readily applied if approached appropriately.

2.6 Indonesia

In addition to the pilot that was discussed in Section 2.1, Suryantini *et al.* (2021) summarized the experience of applying UNFC to six greenfield projects in the Flores Island.

A number of UNFC training events have also been implemented by geothermal consultant Jacobs as part of the GEOINZ development assistance program funded by the New Zealand Government. These were typically as part of wider capacity building workshops of 2-3 days in duration for entities within the Directorate of Geothermal, Ministry of Energy and Mineral Resources Indonesia. This interaction with the regulator for geothermal development led to the joint publication of a paper on how UNFC could usefully be applied to Indonesia (Ussher *et al.*, 2018). That work included a possible mapping between the Indonesian standard SNI:6009 (BSN, 2017) for classifying development maturity and indicated how local standards and inventory could potentially be mapped to UNFC for the purpose of international reporting, possibly as an interim measure before any fuller implementation of UNFC.

2.7 Europe

Several case studies of application of UNFC to geothermal energy resources in Europe have been reported in the public domain, including by: Nador and Zilahi-Sebess (2016), Hajto (2016), Conti, Pellegrini and Falcone (2019), Mijnlieff *et al.* (2019), Schifflechner *et al.* (2019), Falcone and Conti (2019) Mijnlieff *et al.* (2021), Kodhelaj (2023). In addition, UNFC has been cited and considered as a reference in geothermal projects funded by the European Union – see Baisch and Wolpert (2021), de Gregorio, Perez and Casillas (2021), the Interreg Danube Translational Programme (2017-2019).

Prior to the publication of the preliminary results of the Dutch nationwide resource classification pilot study by Mijnlieff *et al.* (2019) the results were used in the policy domain to define actions to accelerate the uptake of geothermal energy. From the evaluation it was concluded that in relative data-poor areas, but with heat demand, the uncertainty in the estimate of the geothermal resource potential was too large to define a solid business case. It was decided to embark on the SCAN data-acquisition program (Ter Borgh *et al.*, 2024) consisting of seismic and research wells to reduce geological uncertainty. It is anticipated that the business case for future geothermal exploration activities resulting in operational projects in the data-poor areas becomes favorable with the new data.

A number of public and in-house training courses on geothermal resources assessment have been offered to European clients by GeoLogica Ltd since 2021. By the end of the courses, the attendees learn to appreciate the key differences between quantification and classification, and between UNFC and previous geothermal assessment systems.

3. LESSONS LEARNT FROM WORLDWIDE TRAINING AND IMPLEMENTATION

Following the global dissemination and implementation activities presented in Section 2, the following summarizes key lessons learnt on the applicability of UNFC to geothermal resource assessments and its useability in real contexts.

3.1 UNFC focus on project maturity and what the project can produce rather than "heat in the ground"

UNFC's focus on a feasible project concept or plan and what energy that may produce rather than assessing potential production from "reservoirs" which have a lot more uncertainty has enabled a much more objective and realistic assessment of what can be produced. For early-stage projects the user is forced to consider the total energy production process from subsurface to point of sale / use, and where a project may be located in real terrain. This is in contrast to traditional approaches focused more on energy estimates that may use simple stored heat (or heat-in-place), recovery factors and energy conversion methods that have been widely applied in the past, often resulting in excessive and unrealistic estimates. There is a significant amount of thermal energy in the earth of a great variety of grades and depths, but it is the ability to practically and economically extract such energy that is always the challenge, and the project "lens" brings a measure of practicality and reality to any energy estimates.

The user is also required to indicate project staging which may mean that any broader energy source is developed in stages, often starting with the most certain or viable part and progressively expanding as knowledge is gained. This means that instead of a lumped energy estimate based on some heat anomaly or reservoir, staging of a development can be identifiedm which is useful information for investors and regulators.

To take full advantage of a UNFC project classification, all the evaluated issues defining the final environmental-socio-economic class and technical maturity class can be used to make a project fingerprint. Project fingerprint defines the project's maturity on the different underlying environmental-socio-economic and technical aspects, highlighting any issues that may pose obstacles to the project maturation. Knowing which aspect of the project is a key obstructing element enables policy makers and investors to make informed well-balanced decisions towards their policy actions or investments. **Figure 3** shows an example of project fingerprinting of the Koekoekspolder project in the Netherlands in the exploration and production phases.

It has also been found that there may be value in having simpler "plain language" and brief guidance for assessing the E and F classes for certain types of geothermal projects. In the deep geothermal context, for example, the use of language such as "Ready for exploration drilling" or "Under construction" has impactful meaning and eases the selection of appropriate E or F class that can then be verified by reading the fuller and more formal description for that class.

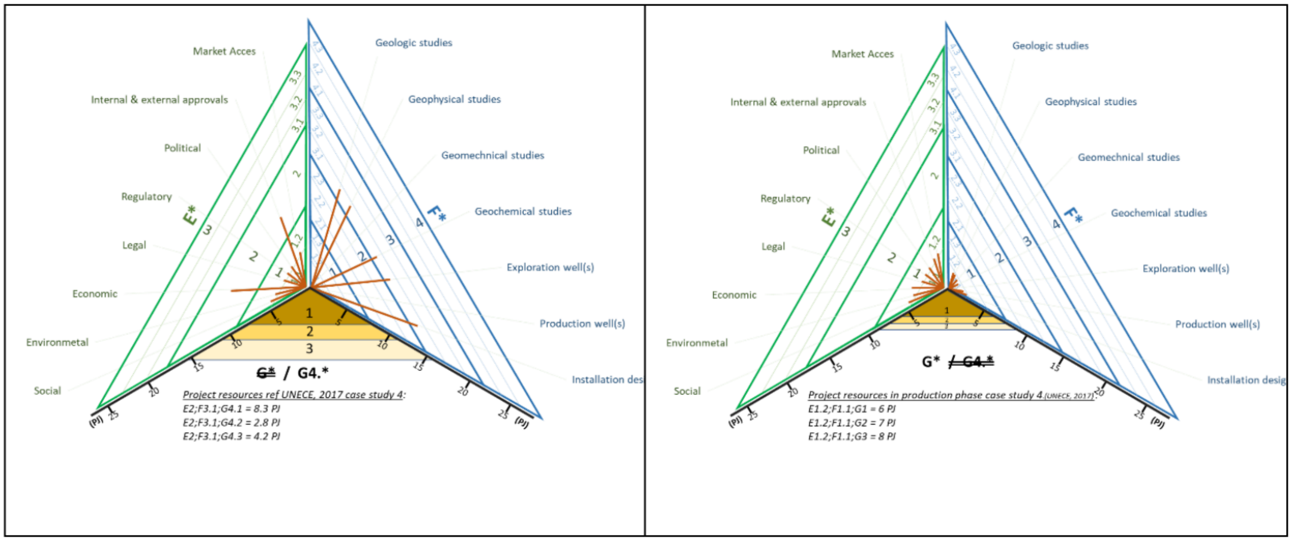


Figure 3: UNFC-project fingerprint of the same case study project before drilling in the exploration phase and after in the production phase. Uncertainty in the latter is related to the project lifetime. (Mijnlieff *et al*., 2019)

3.2 Wider application of classes and additional granularity of sub-classes

In addition to the E, F and G Categories that reflect the separate classification on the three main "axes", UNFC includes indicated classes (viable, potentially viable, non-viable and prospective projects) and some sub-classes that align with common thinking on how projects mature (**Figure 4**). Training and implementation to date has shown this view of UNFC to be far more intuitive for most people considering UNFC for the first time, understanding what the "end game" is for assessing project maturity, and seeing how this may be practically useful in providing a view of a portfolio or inventory, as well as understanding status of any individual project. Experience by some practitioners indicates that having suitable sub-classes for main types of geothermal may be the most appropriate approach, rather than simply reporting E, F and G Categories.

While UNFC standard classes are quite granular for viable projects because of enabling differentiating between, approved for development, under construction, and in operation, there is no differentiation for early-stage exploration of prospective projects (not yet drilled), which are all in one class. However, in practice for deep hydrothermal projects, these undergo multiple stages of surface exploration and could be needing additional surveys, on hold, or be ready to move onto drilling. This is important information for understanding project status. UNFC allows for creating additional sub-classes and there are some attempts underway to meet this need, but the challenge being to make these as universally applicable as possible.

UNFC Classes Defined by Categories and Sub-categories						
Total Products	Produced	Sold or used production				
		Production which is unused or consumed in operations				
		Class	Sub-class	Categories E	Categories F	Categories G
	Known Sources	Viable 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 Viable Projects	Development Pending	2[b]	2.1	1, 2, 3
			Development On Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development Not Viable	3.3	2.3	1, 2, 3
		Remaining products not developed from identified projects		3.3	4	1, 2, 3
	Potential Sources	Prospective Projects	[No sub-classes defined]	3.2	3	4
		Remaining products not developed from prospective projects		3.3	4	4

Figure 4 UNFC classes and sub-classes are proving more meaningful to many users than the UNFC categories (E, F, G) and have proven to be a valuable way of presenting consolidated regional or portfolio assessments (e.g., in Ussher *et al.*, 2023).

3.3 Probability of Discovery

In Falcone *et al.* (2022), the Probability of Discovery (PoD) is defined as '*the chance that further exploration, drilling, and well testing of a Potential Geothermal Energy Source will result in the confirmation of a Known Geothermal Energy Source. This will typically be assessed considering the key factors that are required to achieve a discovery which may include temperature, permeability and fluid chemistry or other relevant parameters that are important for the type of Project planned to evaluate the technical feasibility of the Project*.' The concept of PoD for prospective projects represents the chance that there exists a significant quantity of recoverable thermal energy, suitable for providing heat at rates sufficient to support the project. PoD was introduced in the UNFC geothermal specifications to reflect the high level of uncertainty typical of most conventional types of deep geothermal systems when progressing from surface-based studies to actual drilling and has since proven to have a growing support in the industry, as it can be truly valuable for decision making. This is critical as a potential modifier for energy estimates for prospective projects which can be very high risk, and a low certainty of progressing in further development.

Ussher *et al*. (2024) describe the formalization of a methodology for assessing PoD for hydrothermal prospects that was driven by a specific request from a government-based funding organization in Indonesia to assess PoD as part of their own risk evaluation for lending (sometimes with forgiveness on failure) on exploration drilling programs. In this case, PoD is very much a key part of the lending decision and could factor directly in the financial assessment of loan parameters.

The experience shows that many developers, notably in Indonesia, find PoD important when evaluating and comparing projects in a portfolio. The PoD is also an essential parameter to calculate risked resources if resource assessment is done at national level.

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

Falcone and Conti (2019) already discussed the applicability of UNFC principles to regional and country-level assessments of geothermal energy resources. 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 realistic estimate of potentially recoverable quantities can be made without it. As reported in Falcone *et al.* (2022), '*The creation of notional or hypothetical 'standard' Prospective 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.

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.

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. Developing sustainable energy scenarios involves the fundamental challenge of 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.

Experience so far with this type of assessment has confirmed that while it is indeed challenging to pre-define projects within regional and country-level assessments, even basic project-thinking considerations can make a significant difference. The application of one average recovery factor at regional level, for example, 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.

In 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.* (2022), '*For national resource reporting, the aggregation of individually reported resource estimates from commercial, non-commercial and/or governmental organizations may not cover the total national geothermal energy resources. The creation of notional or hypothetical 'standard' prospective 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 using UNFC is given by Case Study 5, Dutch Rotliegend Play area – Nationwide, which was led by Mijnlieff in Falcone *et al.* (2017), subsequently revisited and expanded by Mijnlieff *et al.* (2019).

3.5 Quantification of geothermal energy resources

Some observers, such as IEA (2024) have noted that UNFC and its geothermal specifications provide no explicit guidance on estimating the recoverable quantities associated to a project, and this has been pointed to as a limitation of UNFC. However, through the experience in applying UNFC globally, it has emerged that the project-based focus, and the related process of identifying probable stages of development for any type of geothermal system / reservoir / source area has meant that there is far less interest in what is theoretically possible from any subsurface source, and much more interest in what a real project can achieve. This puts natural onus on the developer or assessor to define the extraction and surface processes involved till the point where the geothermal energy product will ultimately be sold, transferred, used, or consumed in operations. Defining a technical project from source to reference point and market starts to provide realistic constraints on the range of energy that may be produced from the project.

Subsurface long-term behavior and performance of wells (pumped or natural flow, open-loop or closed-loop, deep or shallow systems) are crucial considerations, but there are such wide range of geological settings and emerging technologies that this needs project-specific detail. There currently exists a wide range of geothermal system types and new technologies including Engineered Geothermal Systems and so-called Advanced Geothermal Systems. Estimating energy extraction from this variety is not something easily mandated when in fact the technology-leading developers should be providing the evidence-based guidance on what is achievable. What could be provided more readily is guidance on dealing with reservoir (source) uncertainties, multiple concept models for the source, how to consider project uncertainties such as development size and lifetimes, and requirements for linking the subsurface source performance to that of the surface production facilities (in principle terms). This, in combination with the project concept, provides strong guidance on estimating recoverable quantities.

A wide range of peer-reviewed and open-access references exist that offer the state-of-the-art on quantification best practices (e.g., paper databases from the World Geothermal Congress, the Stanford Geothermal Workshop, the European Geothermal Congress, several geothermal and geo-energy journals). Evaluators are best placed to select and apply best practices that are most suitable to a given project type and level of project maturity, and recommendations are provided separately for organizations or entities such as national governments, financial institutions and companies who wish to establish appropriate quality assurance mechanisms, qualification criteria and/or disclosure obligations that can be adopted in circumstances where competency requirements are considered desirable (UNECE, 2022).

In addition, UNFC and the geothermal specifications provide guidance on how to categorize product quantity estimates, which in turn reflects quantification approaches. Quantity estimates '*may be categorized discretely, based on the degree of confidence in the estimates (high, moderate and low confidence, respectively) based on direct evidence. Alternatively, they may be categorized as a range of uncertainty as reflected by either (i) three specific deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50 and P10) are selected. In all cases, the product quantity estimates are those associated with a project.' UNFC further clarifies that 'the G-axis categories are intended to reflect all significant uncertainties (e.g. source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimate forecast for the project. Uncertainties include variability, intermittency and the efficiency of the development and operation (where relevant). Typically, the various uncertainties will combine to provide a full range of outcomes*.' Users are encouraged to indicate the production profile of geothermal energy products, and the project lifetime should be indicated to support each estimate. Estimating energy quantities will remain a challenge due to the subsurface nature of geothermal sources, the fact that heat is distributed diffusely through the earth rather than in finite accumulations, the many different ways of connecting the subsurface with the surface, and the wide range on engineering solutions to convert raw thermal energy into useable energy products. Nonetheless, the UNFC project-based approach and its handling of project maturity has proven to be a big step forward in practical definition of what can realistically be expected to be produced from geothermal projects at all stages of development.

3.6 Rate-based energy (MW) estimates versus total energy (PJ)

UNFC provides for estimating the total resource, which in UNFC terms is the cumulative quantities of geothermal energy products that will be extracted from the source from the effective date of the evaluation till the end of the project lifetime. The standard reporting for this is in Joule (J) or multiples of the Joule, e.g. petajoules (PJ) , but this is not a common way of viewing energy production especially for other renewable energy projects, where the rate of production (MW or GWh/year) is typically a more common way of viewing production, as this is important in terms of meeting capacity demands in any market. Lifetime is important in terms of economics, but markets are interested in demand.

Global training and implementation experience has shown that it is most practical to talk in terms of rate based assessments such as MW(e) or MW(th) in discussing the project sizing and behavior, and to consider the production profile expected over the life of the project that would include annual variations, major maintenance and possible source decline later in the project life. This profile can be integrated into PJ via a simple assessment such as considering MW-years of production. A project summary is typically presented that is both rate-based and total PJ, and standardization on doing this is useful for all renewable energy types that may be reported under UNFC.

3.7 Application to thermal / direct heat including GSHP

Thermal/direct use geothermal projects, including ground-source heat pumps (GSHPs), combined heat and power (CHP) and cascaded uses, present specific challenges for application under UNFC. Although very common and potentially applicable worldwide, these systems are often small to medium in scale, typically managed directly by owners and contractors on a one-to-one basis, without the need for a formal classification or communication framework. In contrast, utility-scale high-capacity thermal/direct use geothermal projects—such as district heating and cooling networks (DHCN) or large underground thermal energy storage (UTES) systems—benefit more clearly from the application of UNFC. These larger systems necessitate territorial planning, surface and subsurface site characterization, financing from the private and public sectors, and effective communication with local communities, political and administrative representatives. Such requirements align closely with the broader goals of UNFC, emphasizing the need for systematic classification and language.

According to UNFC principles, geothermal projects must be comprehensively described to assess environmental-socio-economic viability, technical feasibility, and confidence levels. Unlike single-source geothermal power plants, thermal projects often integrate into more complex, hybrid systems designed to optimize cost-benefit ratio of the geothermal product(s) compared with capital expenditure (CAPEX) based on alternative/backup heat generation systems and other energy sources. A critical aspect of UNFC classification is the definition of reference points, which represent where geothermal energy products are sold, used, or delivered. While straightforward for power projects (e.g., grid connections), identifying reference points in thermal projects is more challenging due to their complex configurations.

The 2022 update of the UNFC geothermal specifications addresses this complexity by introducing intermediate nodes, i.e. specific points within a project where intermediate quantities, such as external energy inputs or outputs, are introduced or occur. Examples of cases benefitting from clarity on intermediate quantities have been published (Falcone *et al.* 2017, Conti *et. al* 2019) and include GSHPs systems, aquifer thermal energy storage (ATES) and DHCNs, where heat exchange with the underground is clearly declared and classified separately from energy delivered to the final user, and from energy consumption for compressors and backup generators.

Standardizing the definitions of reference points and intermediate nodes is also crucial for ensuring proper and correct data aggregation across different projects at the regional or national level (Falcone and Conti, 2019). A clear-defined aggregation process preserves the consistency and reliability of aggregated energy quantities, providing a robust base for territorial energy planning, facilitates informed decision-making, and enhances effective resource management, ensuring that geothermal energy projects are accurately represented and communicated among all the stakeholders and the general public.

3.8 Data availability and language

Training courses and workshops held in countries speaking a language other than English have highlighted language barriers to the adoption of UNFC documents. To address this issue, and specifically following the experience in the SICA region, a translation into Spanish of the original UNFC geothermal specifications was provided under the framework of the German Cooperation, Project on the Identification of Geothermal Reservoirs in Central America, implemented by the Federal Institute of Geosciences and Natural Resources of Germany (BGR). However, the updated 2022 version of the geothermal specifications is currently available in English only. Official translations of UN documents are sometimes not possible for longer technical reports or specialized guidance documents. However, key publications, such as the UNFC main document, are translated into all six official UN languages (English, French, Spanish, Russian, Arabic, and Chinese). Other technical specifications and supplementary guidelines are typically published in English due to resource constraints, but may be translated based on demand, available funding, or support from partner organizations.

Data availability and accessibility can often constrain resource assessments, e.g. when the entities carrying out the assessment are not the primary owners of the data, including when relevant data come from a different sector (e.g., oil and gas) and reside with the corresponding operators. While in countries like the Netherlands subsurface data is publicly available, this is not the case in many other countries. Lack of geothermal data such as maps, temperature, water chemistry, thermal conductivity, aquifer depth and permeability limits the effective deployment of geothermal projects. Clearly, this is not a UNFC-related issues, but a general barrier to unlocking the significant geothermal potential of the world.

3.9 Supplementary documents, tools and checklists

Experience so far has shown that most geothermal end-users, when first approaching UNFC, are not aware of the existence of additional UNFC guidelines for implementation, including those on project definition, competent person, social and environmental considerations, and application to commercial assessments. This additional guidance is freely available via the UNECE website (UNECE, 2025) and is directly relevant to geothermal resources. Since all these documents are live, subject to periodic updates at different points in time, they are not incorporated into one master document. Based on this learnt lesson, UNFC training and workshops now include pointing to and using these additional guidelines.

UNFC and its application specifications are not prescriptive on how to prepare UNFC "reports" that summarize key information that is used to define the specific "project" and guide the classification, and there is little guidance on how to present final classifications. This means that users are often not sure where to start, how to conduct an assessment, and how to report it. Worldwide training and implementation has highlighted the need to use various supporting tools such as templates, checklists, and reporting proforma. There have also been decision tools built to help guide the classification process.

Short checklists and templates for capturing key elements of the project description proved very useful in the initial UNFC training workshops in 2018 and 2019 and a proforma reporting template was used to report the final project examples that were completed (Beardsmore *et al.*, 2021). This approach has been continued in most later applications as described in Section 2. The reporting template employed for the Waikato Region inventory in New Zealand (Ussher *et al.*, 2023) used a Word-based template allowing capture of text and graphic content while also providing guidance to the user for each aspect of the project, and resulted in concise summaries for each project of about 4 to 6 pages including the classification and energy estimates (**Figure 5**). This summary is sufficient to provide the description basis for a formal classification as required by UNFC and is relatively easy to prepare if the author knows their project. Such templates also quickly highlight gaps of knowledge that may need further evaluation before completing a classification. Updated versions of the reporting proforma and the report checklist (**Figure 6**) were used during an in-house training delivered through IGA at the end of 2024 to a specialized investment organization that funds geothermal development globally. The team of 15 international professionals worked in sub-groups to discuss and classify a number of notionalized projects that their organization was working on; within two hours, including a full-team brainstorming discussion, each of the project was successfully classified, highlighting how the granularity offered by UNFC sub-categories allows distinction of projects even when they would all typically be regarded as 'exploration projects'.

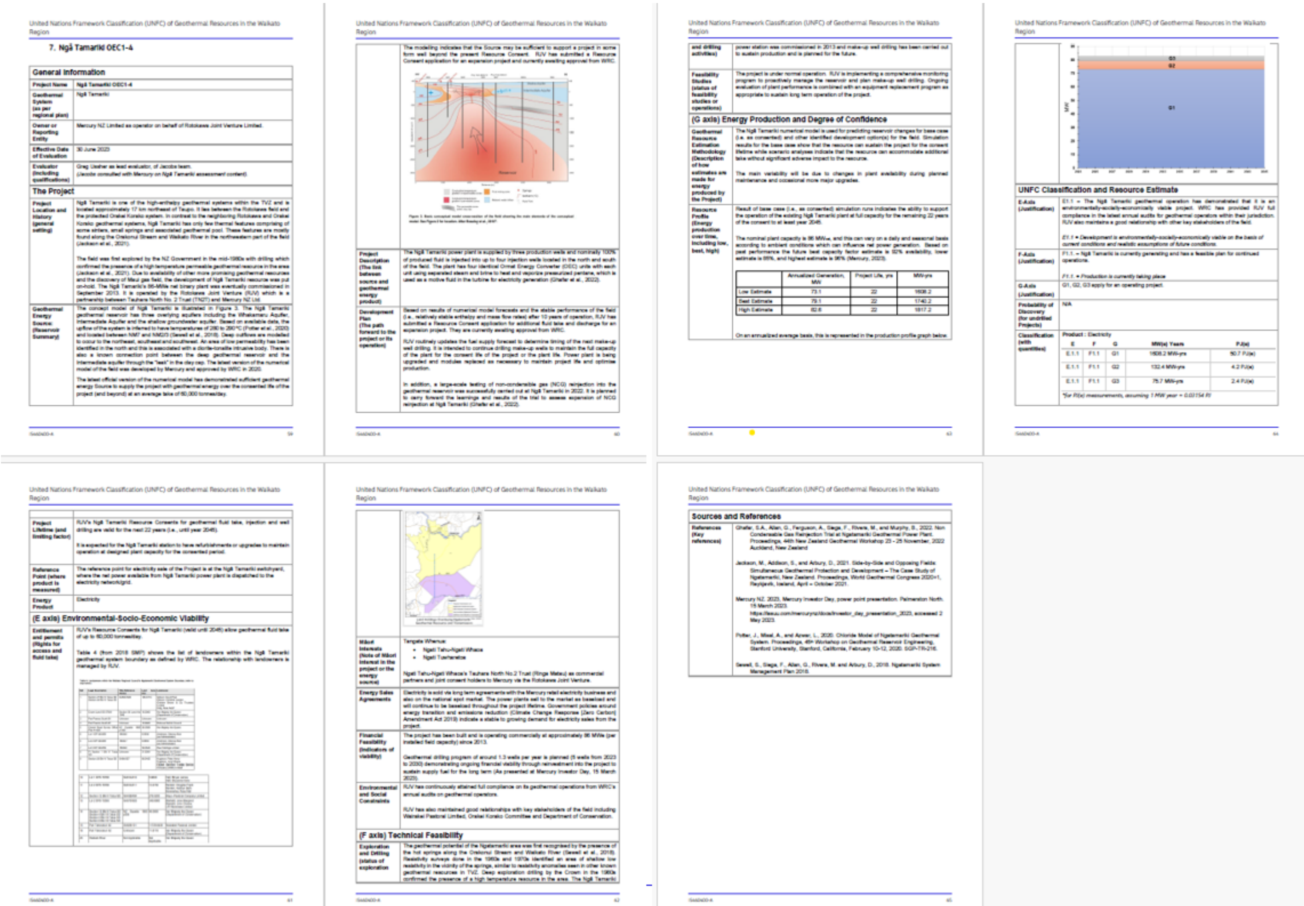
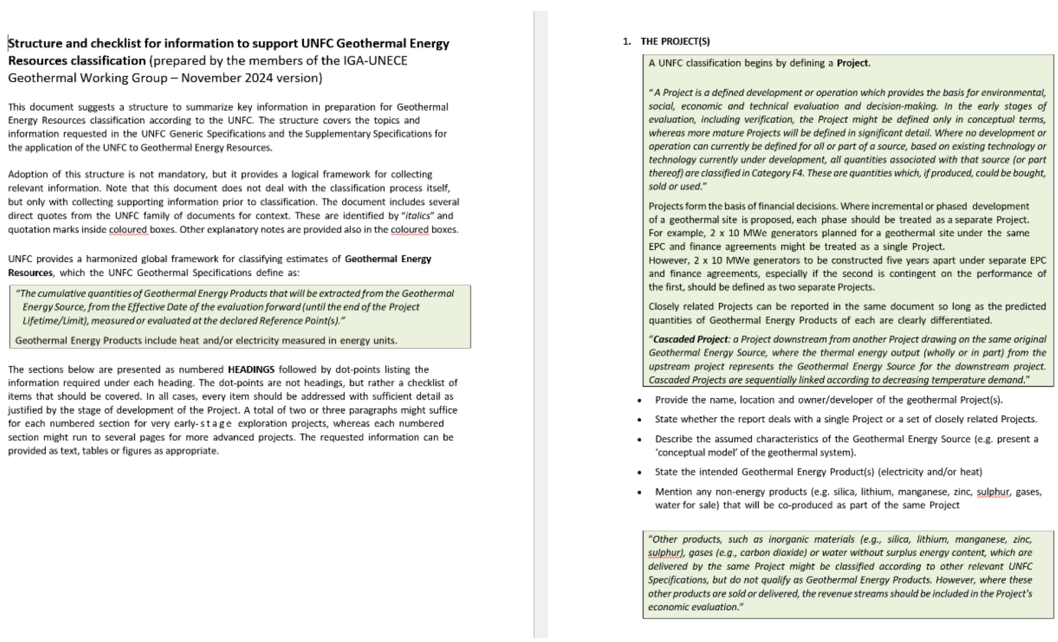


Figure 5: Example project summary from the Waikato Region UNFC inventory in 2023, showing the use of a standard reporting template that helps focus the collation and summarizing of key information needed to support a UNFC assessment (Ussher *et al.*, 2023).



Structure and checklist for information to support UNFC Geothermal Energy Resources classification (prepared by the members of the IGA-UNECE Geothermal Working Group – November 2024 version)

This document suggests a structure to summarize key information in preparation for Geothermal Energy Resources classification according to the UNFC. The structure covers the topics and information requested in the UNFC Generic Specifications and the Supplementary Specifications for the application of the UNFC to Geothermal Energy Resources.

Adoption of this structure is not mandatory, but it provides a logical framework for collecting relevant information. Note that this document does not deal with the classification process itself, but only with collecting supporting information prior to classification. The document includes several direct quotes from the UNFC family of documents for context. These are identified by "*italics*" and quotation marks inside coloured boxes. Other explanatory notes are provided also in the coloured boxes.

UNFC provides a harmonized global framework for classifying estimates of **Geothermal Energy Resources**, which the UNFC Geothermal Specifications define as:

"The cumulative quantities of Geothermal Energy Products that will be extracted from the Geothermal Energy Source, from the Effective Date of the evaluation forward (until the end of the Project Lifetime/Limit), measured or evaluated at the declared Reference Point(s)."

Geothermal Energy Products include heat and/or electricity measured in energy units.

The sections below are presented as numbered **HEADINGS** followed by dot-points listing the information required under each heading. The dot-points are not headings, but rather a checklist of items that should be covered. In all cases, every item should be addressed with sufficient detail as justified by the stage of development of the Project. A total of two or three paragraphs might suffice for each numbered section for very early-stage exploration projects, whereas each numbered section might run to several pages for more advanced projects. The requested information can be provided as text, tables or figures as appropriate.

1. **THE PROJECT(S)**

A UNFC classification begins by defining a **Project**.

"A Project is a defined development or operation which provides the basis for environmental, social, economic and technical evaluation and decision-making. In the early stages of evaluation, including verification, the Project might be defined only in conceptual terms, whereas more mature Projects will be defined in significant detail. Where no development or operation can currently be defined for all or part of a source, based on existing technology or technology currently under development, all quantities associated with that source (or part thereof) are classified in Category F4. These are quantities which, if produced, could be bought, sold or used."

Projects form the basis of financial decisions. Where incremental or phased development of a geothermal site is proposed, each phase should be treated as a separate Project. For example, 2 x 10 MWe generators planned for a geothermal site under the same EPC and finance agreements might be treated as a single Project. However, 2 x 10 MWe generators to be constructed five years apart under separate EPC and finance agreements, especially if the second is contingent on the performance of the first, should be defined as two separate Projects.

Closely related Projects can be reported in the same document so long as the predicted quantities of Geothermal Energy Products of each are clearly differentiated.

"***Cascaded Project**: a Project downstream from another Project drawing on the same original Geothermal Energy Source, where the thermal energy output (wholly or in part) from the upstream project represents the Geothermal Energy Source for the downstream project. Cascaded Projects are sequentially linked according to decreasing temperature demand."*

- Provide the name, location and owner/developer of the geothermal Project(s).
- State whether the report deals with a single Project or a set of closely related Projects.
- Describe the assumed characteristics of the Geothermal Energy Source (e.g. present a 'conceptual model' of the geothermal system).
- State the intended Geothermal Energy Product(s) (electricity and/or heat)
- Mention any non-energy products (e.g. silica, lithium, manganese, zinc, sulphur, gases, water for sale) that will be co-produced as part of the same Project

"Other products, such as inorganic materials (e.g., silica, lithium, manganese, zinc, sulphur), gases (e.g., carbon dioxide) or water without surplus energy content, which are delivered by the same Project might be classified according to other relevant UNFC Specifications, but do not qualify as Geothermal Energy Products. However, where these other products are sold or delivered, the revenue streams should be included in the Project's economic evaluation."

Figure 6: Excerpt from the reporting guidance and checklist used in trainings/workshops to facilitate UNFC classification for geothermal resources (previously reported by Beardsmore *et al.*, 2021 and updated in 2024 by the IGA-UNECE Geothermal Working Group).

Since their original release in 2016, the UNFC geothermal specifications have included decision trees to aid the classification of geothermal projects. The decision trees were developed by Mijnlieff, with contributions from the IGA UNFC ad hoc committee in their current form. For each of the three UNFC axes (E, F and G), a separate decision tree is provided. By following the arrows from decision box to decision box, the user is guided towards the most suitable classification at the highest hierarchical level for the given axis. For the E Axis, a loop is introduced because there is potentially a suite of issues pertaining to the environmental, social, economic, legal, etc. domains, which need to be resolved for the project to progress. There will usually be multiple contingencies and the overall project E-classification should be that of the lowest ranking one. Project activities as used in the F-axis classification definitions are related to the 'technical' evaluations that are performed and documented. For geothermal application these include: (a) geological studies; (b) geophysical studies; (c) geochemical studies; (d) geomechanical studies; (e) reservoir/subsurface modeling studies; (f) well/borehole drilling and completion studies; (g) surface equipment/infrastructure studies; (h) siting/logistics. The studies with the lowest maturity define the final score. **Figure 7** shows the decision tree for the E-axis.

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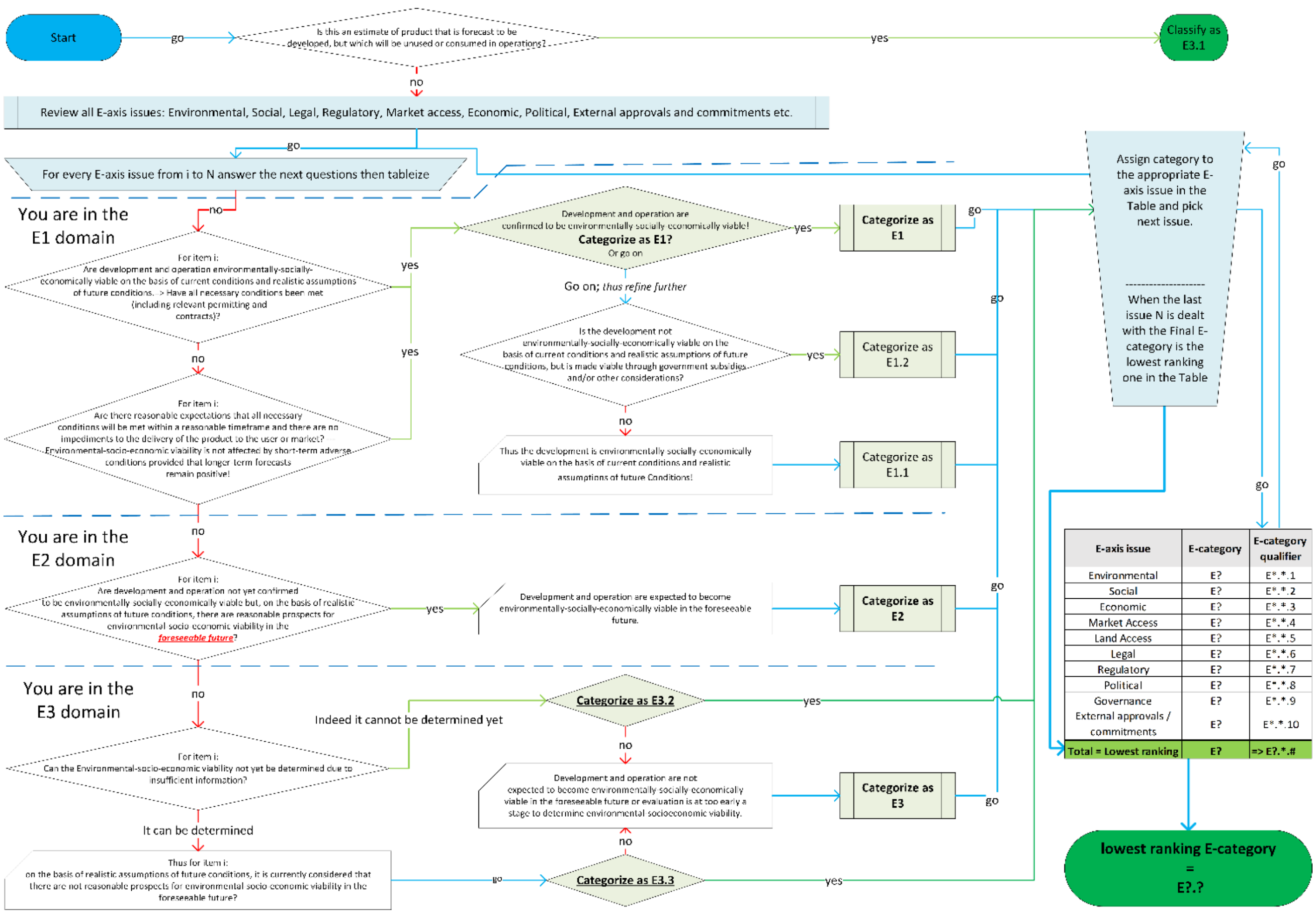

Figure 7: Decision tree for the E-axis (Mijnlieff, in Falcone *et al.*, 2022).

UNFC allows the use of such tools. They have all proven to aid users with implementation, with different level of effectiveness in different contexts and with different audiences. They continue being refined and tailored as experience with their use increases.

3.9 Synergies with the oil and gas sector

In March 2023, a Society of Petroleum Engineers (SPE) Live event took place, where the application of UNFC to geothermal energy resources was discussed, including why we need a resource assessment framework for geothermal, and what the synergies with the oil and gas sector are in this space (Falcone and Lines, 2023).

In August 2023, an invited presentation on the application of UNFC to geothermal energy resources was given in Galveston, USA at the SPE Workshop on Reservoir Aspects of Geothermal Systems (Falcone, 2023), with c.a. 100 participants.

A 1-day training course on Geothermal Energy – From Potential to Implementation, with a dedicated section on UNFC, was offered to an international audience of oil and gas professionals as part of the program of the SPE Europe Energy Conference and Exhibition in Turin, Italy, 26-28 June 2024. The 23 international participants discussed similarities and differences on resource assessment across geo-energy sectors, identifying areas where future research efforts should be addressed to accelerate the energy transition. At the same event, Jones *et al.* (2024) presented an SPE paper on how resource classification systems can enable the energy transition. They highlighted that key project metrics are already included in UNFC, and that additional common information can be incorporated for tailored decisions frameworks. This can support dialogue between stakeholders to develop effective public-private partnerships and meet the demands of the energy transition. This includes the potential for professional bodies (such as SPE), academia and industry to contribute to the operationalization of expanded project metrics.

Until recently, SPE had a representative serving on the EGRM Bureau, which is responsible for managing and progressing all streams of the EGRM's work.

These interactions have shown that the project-based approach of UNFC is something that the oil and gas sector is already well accustomed to and that while some geological plays and end-uses are unique to the geothermal sector, the risk assessment workflows are very similar. In fact, there already exists a 2023 Bridging Document between the Petroleum Resources Management System (PRMS) and UNFC (UNECE, 2023), which supersedes and replaces a previous Bridging Document between the 2009 edition of UNFC and the 2007 publication of PRMS.

4. CONCLUSIONS

Since the original publication of the specifications for the application of UNFC to geothermal energy resources, a significant amount of training, dissemination and implementation activities have taken place worldwide.

Application over 8 years has found ways to facilitate UNFC classification and has proven that classification can be done readily with basic but structured training. Additional guidance and tools have been developed to help that process and are key for compiling concise information on projects that is valuable for all stakeholders. Continued application provides the opportunity to refine further the application tools on this simplification path.

Geothermal seems to be ahead of other renewable energy sectors in adopting UNFC. Given that geothermal projects tend to work in the same local markets, and under the same local policies and regulations as other renewables, UNFC offers the unique opportunity for all renewable energy sectors to work collectively under a common system. In this regard, the context of renewable energy drivers and local markets differs from the global market for mineral and petroleum resources.

Quantification is a key component of resource assessments, but as multiple best practices already exist, and given the significant variety and continuous evolution of geothermal systems and technologies, it is neither possible nor advisable to ‘standardize’ quantification. UNFC offers guidance on how to categorize product quantity estimates, which in turn reflects quantification approaches, which may be deterministic (or scenario-based), or probabilistic. Uncertainties in the estimates combine to provide a full range of outcomes. In addition, users are encouraged to include the production profile of geothermal energy products from the date of the evaluation to the end of the project lifetime. Estimating quantities remains a challenge for all energy resources, but the UNFC project-based approach and its handling of project maturity naturally lends itself to practical identification of what a project (notional or more mature) can realistically produce.

The focus on project maturity represents the core value of using UNFC in presenting a clear picture of what can be achieved in the near term which is particularly applicable for markets, portfolio managers and regulators who are typically not as interested in absolute “reserves” quantities as they are in what can be realized in practical planning terms, and with which level of risk and uncertainty. The project maturity approach also allows projects and portfolios fingerprinting to track how these progress over time, and to identify and resolve potential barriers to progression.

The intense training, dissemination and implementation activities that have taken place over the past 8 years have highlighted the need to systematically ‘train the trainers’ to ensure consistency in the interpretation of the core UNFC principles and to facilitate application to country-/region-specific regulatory and market requirements.

All UNFC documents, including the geothermal specifications, are ‘live’ documents, subject to periodic updates. The energy landscape is ever changing and increasingly challenged by the urgency of climate change and sustainable development. Experience with working closely with end-users has shown that sustainability key performance indicators (KPIs) are at least on par with economic and technical viability of projects, if not the make-it-or-break-it factors. The E-axis of UNFC and its subcategories offer a unique opportunity to expand granularity on these key aspects, leveraging bespoke criteria that are more relevant to different types of energy resources and different geographical contexts. With the adoption of UNFC in Africa under the AMREC-PARC system, for example, UNFC principles are proving to be a vehicle for self-determination in the face of ongoing “economic colonialism” by other nations and international industry, and are already empowering the continent to address specific deficiencies in the management of minerals and petroleum resources.

Most ‘first-time’ geothermal end-users are not aware of the existence of additional UNFC guidance on project definition, competent person, social and environmental considerations, and application to commercial assessments. Thus, UNFC training and implementation workshops need to specifically point to those and show how and when they can be used to facilitate classification.

The cooperation between UNECE and IGA has proven to be key towards not only the development, but also the ongoing implementation of UNFC globally. The broader applicability of UNFC to all resources, coupled with the geothermal-specific expertise of IGA has allowed top-down and bottom-up thinking to converge to a classification framework that is compliant with different resource types, while also addressing the specific needs of the geothermal sector. Both UNECE and IGA are super-national and multi-stakeholder platforms for knowledge exchange and open collaboration. Through their joint global outreach, it has been possible to secure input and support by IRENA, ESMAP, Geothermal Rising, DOE, GEA, IEA-GIA and EGEC at various stages of development and implementation of UNFC for geothermal energy resources.

The successful application of UNFC to geothermal energy has demonstrated its value as a globally harmonized tool for transparent, sustainable, and efficient resource management. With UNFC now integrated into regional and national frameworks, including in Australia and the SICA region, and its alignment with AMV, PARC, and EU CRMA, further collaboration is essential to scale up implementation.

Looking ahead, UNECE and IGA will continue strengthening their partnership in advancing UNFC and UNRMS for geothermal energy.

The next steps include:

- Expanding adoption by engaging national governments and regulatory bodies to integrate UNFC into policy frameworks, permitting processes, and investment strategies.

- Enhancing capacity-building efforts through training programs, technical workshops, and pilot projects to improve the practical application of UNFC for geothermal project assessment.

- Strengthening collaboration between the geothermal sector, financial institutions, and policymakers to promote sustainable investment and risk reduction in geothermal energy development.

Governments, local authorities, industry stakeholders, geothermal associations, communities and research institutions are invited to collaborate in scaling up the use of UNFC to support sustainable, transparent, and equitable geothermal resource management. Use cases, feedback and engagement from experts and practitioners in the field is particularly welcome to further refine the classification and reporting processes, and to collectively ensure that geothermal energy plays a pivotal role in the global energy transition.

REFERENCES

AMDC (2024) The Pan African Public Reporting Standard for Minerals and Energy Resources. A publication by the African Union. https://au.int/sites/default/files/documents/43674-doc-PARC_EN.pdf

Australian Geothermal Association (AGA) (2023) UNFC Resource Assessment Update, https://www.australiangeothermal.org.au/post/unfc-resource-assessment-update [Accessed 9th January 2025].

Badan Standardisasi Nasional, BSN (2017) SNI 6009: 2017. Klasifikasi sumber daya dan cadangan energy panas bumi Indonesia.

Baisch, C. and Wolpert, P. (2021) Draft Structure of a Play Type Independent Geothermal ExplWhuilke slow to oration Risk Mitigation Scheme, CROWDTHERMAL DELIVERABLE 3.4, https://www.crowdthermalproject.eu/wp-content/uploads/2021/03/CROWDTHERMAL-D3.4_GeoT_Final.pdf, accessed on 9 January 2025.

Beardsmore, G.R. (2024) A review of hot sedimentary aquifer geothermal resources in Australia. New Zealand Journal of Geology and Geophysics, 1–21. https://doi.org/10.1080/00288306.2024.2374065.

Beardsmore, G., Ali, A., Brommer, M., Chen, H., Conti, P., Falcone, G., Fridriksson, T., Hogarth, R., Mijnlieff, H., Rumberg, G. and Ussher, G. (2021) UNFC Resource Classification Applied to Real World Geothermal Projects: Outcomes from an Education and Implementation Pilot Program. In: World Geothermal Conference 2020+1, Reykjavik, Iceland, 24-27 October 2021.

Bromley, CJ, Rae, A.J., Alcaraz, S.A., Kissling, WM, Rivera, J.M. (2024) Inventory of New Zealand supercritical geothermal resources. Lower Hutt (NZ): GNS Science. 29 p. (GNS Science report; 2023/50). https://doi:10.21420/053X-5618.

Cariaga, C. (2023) UNFC applied for geothermal inventory at Waikato Region, New Zealand. Article in Think GeoEnergy. https://www.thinkgeoenergy.com/unfc-applied-for-geothermal-inventory-at-waikato-region-new-zealand/

Chaves, A. (2023) Informe Técnico: Taller Regional sobre la Clasificación Marco de las Naciones Unidas (CMNU) en la región SICA, Yacimientos II (BGR-SICA), Costa Rica. Informe taller CMNU 2023 - Portal del SICA , accessed on 20 January 2025.

Conti, P., Pellegrini, M., Falcone, G. (2019) Application of the UNFC Classification to Open-Loop Ground Source Heat Pump Systems: A Case Study, European Geothermal Congress, The Hague, Netherlands, 11-14th June 2019.

Consejo de Ministros de Energía del SICA- GTG (2022) Estado actual de la geotermia en la región de los paises miembros del SICA 2021. p. 10, 37. San Salvador 2022. Compendio Regional - Diagnóstico de la situación actual de la geotermia 2021 - Portal del SICA [Accessed 20th January 2025].

de Gregorio, M., Perez, P. and Casillas, A. (2021) Case Study Assessment Protocol, CROWDTHERMAL DELIVERABLE D5.1, https://www.crowdthermalproject.eu/wp-content/uploads/2021/11/CROWDTHERMAL-Deliverable-D5.1-Case-study-assesment-protocol-v4-10-2021.pdf [Accessed 9th January 2025].

Falcone, G. (2023) Application of UNFC to geothermal energy resources, SPE Workshop: Reservoir Aspects of Geothermal Systems, Galveston, Texas, 15-16 August 2023.

Falcone, G. and Conti, P. (2019) Regional and Country-Level Assessments of Geothermal Energy Potential Based on UNFC Principles, European Geothermal Congress, The Hague, Netherlands, 11-14th June 2019.

Falcone, G., Antics, M., Baria, R., Bayrante, L., Conti, P., Grant, M., Hogarth, R., Juliusson, E., Mijnlieff, H., Nádor, A., Ussher, G., and Young, K., with Beardsmore, G. and Rueter, H. as observers (2016) Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC 2009) to Geothermal Energy Resources. Documentation. Economic Commission for Europe (ECE).

Falcone, G., Antics, M., Baria, R., Bayrante, L., Conti, P., Grant, M., Hogarth, R., Juliusson, E., Mijnlieff, H., Nádor, A., Ussher, G., and Young, K., with Beardsmore, G. and Rueter, H. as observers (2017) Application of the United Nations Framework Classification for Resources (UNFC) to Geothermal Energy Resources: Selected case studies. Documentation. Economic Commission for Europe (ECE).

Falcone, G., Beardsmore, G., Conti, P., Hogarth, R., Kastl, S., Mijnlieff, H., Nádor, A., Schifflechner, C. and Ussher, G. (2022) Supplementary Specifications for the Application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resources. United Nations, Geneva.

Falcone, G. and Lines, T. (2023) SPE Live: Application of the UNFC to Geothermal Energy Resources, Gioia Falcone - moderated by Tim Lines, SPE Live: Application of the UNFC to Geothermal Energy Resources – SPE Energy Stream [Accessed 27th January 2025]

Geoscience Technical Group (GTG) (2024) Informe Técnico Taller Regional sobre la Clasificación Marco de las Naciones Unidas (CMNU) en la región SICA, Informe taller CMNU 2023, 24 April 2024, https://www.sica.int/documentos/informe-taller-cmnu-2023_1_133890.html [Accessed 30th January 2025].

Hajto, M. (2016) A brief glossary of Polish and the UNFC-2009 classifications and nomenclature of geothermal resources assessment, European Geothermal Congress, Strasbourg, France, 19-24 September 2016.

International Energy Agency (IEA) (2024) The Future of Geothermal Energy, December 2024.

Interreg Danube Transnational Programme (2017-2019) Classification of geothermal resources / reserves, https://www.e.lea-pomurje.si/go/906/Classification-of-geothermal-resources-reserves.html [Accessed 9th January 2025].

IRENA and IGA (2021) United Nations Framework Classification for Geothermal Energy: Pilot applications in the Caribbean, Ethiopia and Indonesia, International Renewable Energy Agency, Abu Dhabi, International Geothermal Association, Bonn. ISBN 978-92-9260-297-0

Jones, A., Ahadjie, J., Betts, I., Brinnen, K., Hartung, M., Heiberg, S., and Ingvald, E. (2024) How Resource Classification Systems can Enable the Energy Transition. Paper presented at the SPE Europe Energy Conference and Exhibition, Turin, Italy, June 2024. doi: https://doi.org/10.2118/220043-MS

Kodhelaj, N. (2023) Report on Assessment of the geothermal resources of Albania, https://unece.org/sites/default/files/2023-06/UNFC-UNRMS-Case-Study%20Albania_Final_Clean.pdf [Accessed 9th January 2025].

Mijnlieff, H., van Kempen, B., Tolsma, S., de Vries, C., Esteves Martins, J., Veldkamp, H., Struijk, M., Vrijlandt, M. (2019) Dutch Geothermal Resource Reporting: A First Attempt of Dutch Nationwide Geothermal Resource Using the UNFC Resource Classification System. Status Date January 2019, European Geothermal Congress, The Hague, Netherlands, 11-14th June 2019.

Mijnlieff, H., van Kempen, B., Tolsma, S., de Vries, C., Esteves Martins, J., Veldkamp, H., Struijk, M., Vrijlandt, M., van Wees, JD (2021) The Dutch Geothermal Resource Base: Classified Using UNFC Resource Classification System and Its Potential to Meet the Dutch Geothermal Ambition. In: World Geothermal Conference 2020+1, Reykjavik, Iceland, 24-27 October 2021. https://www.worldgeothermal.org/pdf/IGAstandard/WGC/2020//16062.pdf

Nador, A., Zilahi-Sebess, L. (2016) Entering geothermal energy into the UNFC-2009 classification system: case studies of direct-use projects from Hungary, European Geothermal Congress, Strasbourg, France, 19-24 September 2016.

Nyange, M. (2024) Leveraging United Nations Framework Classification (UNFC) Geothermal Classification Standards for Enhanced Geothermal Project Evaluation and Prioritization. Proceedings, 10th African Rift Geothermal Conference. Dar es Salaam, Tanzania, 23-25 October 2024.

O'Sullivan, J. (2023) Geothermal Project Management Short Course 2023. Article in New Zealand Geothermal Association News. https://www.nzgeothermal.org.nz/news--events/geothermal-project-management-short-course-2023/

Queensland Government (2022) Geothermal Energy Regulation 2022, Subordinate Legislation 2022 No. 112 made under the Geothermal Energy Act 2010 Greenhouse Gas Storage Act 2009.

Resource Management Act (1991) https://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html [Accessed 30th January 2025]

Schifflechner, C., Eyerer, S., Alonso Alvarez, P., Wieland, C., Spliethoff, H. (2019) Evaluating the South German Molasse Basin's geothermal potential by means of the UNFC 2009 Classification, European Geothermal Congress, The Hague, Netherlands, 11-14th June 2019.

Suryantini, N., Beardsmore, G., Widiatmoro, T., Risdianto, D., Firdaus Al Hakim, M., Bakti Pratama, A., Yesy Sianipar, J., Br Sibarani, B., Wibowo, H., Afuar, W., T Prabata, W., Rivelino, R., Trisna Hutama, R. (2021) Application of the United Nations Framework Classification for Resources (UNFC) to Geothermal Energy Reources; Experiences from Six Greenfield Projects in Flores Island, Indonesia. In: World Geothermal Conference 2020+1, Reykjavik, Iceland, 24-27 October 2021.

Ter Borgh, M., Van Lochem, H., JanszenA. And Brussée, M. (2024) Geothermal Exploration in the Netherlands: the SCAN Programme, Fifth EAGE Global Energy Transition Conference & Exhibition (GET 2024), Nov 2024, Volume 2024, p.1 – 5.

Torio Henriquez, E. and Chaves, A. (2023) UNFC for Geothermal Resources Classification in the SICA Region. Case Studies: El Salvador and Costa Rica. Second EAGE Workshop on Geothermal Energy in Latin America, Nov 2023, Volume 2023, p.1 – 6.

UNECE (2022) Guidance Note on Competency Requirements for the Estimation, Classification and Management of Resources, 25 October 2022.

UNECE (2023) Bridging Document between the Petroleum Resources Management System and the United Nations Framework Classification for Resources 2023 Update, 28 April 2023.

UNECE (2025) UNFC Documents, https://unece.org/sustainable-energy/sustainable-resource-management/unfc-documents#accordion_2 [Accessed 27th January 2025].

Ussher, G., Quinlivan, P., Febrianto, R. and Purwanto, E. H. (2018) Application of the UNFC Geothermal Specifications in Indonesia. Proceedings, The 6th Indonesia International Geothermal Convention & Exhibition (IIGCE) 2018.

Ussher, G., Lebe, J.L., Calibugan, A., Brotheridge, J., Quinao, J., Hendri, R., and McLeod, J. (2023) Application of the United Nations Framework Classification for geothermal projects in the Waikato region. Proceedings 45th New Zealand Geothermal Workshop.

Ussher, G., Calibugan, A. and McDowell. J. (2024) Probability of Discovery as a Useful Concept for Communicating Exploration Drilling Uncertainty. GRC Transactions, Vol. 48, 2024.

Verma, A., and Pruess, K. (1986) Enhancement of Steam Phase Relative Permeability Due to Phase Transformation Effects in Porous Media, Proceedings, 11th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA.

Wang, C.T., and Horne, R.N. (1999), Boiling Flow in a Horizontal Fracture, Geothermics, 29, (1999), 759-772.

Yacimientos II -BGR-SICA (2024) Yacimientos II 2020-2024: La CMNU- Clasificación Marco ONU, p. 9-10. Managua, 2024