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Application of the UNFC classification to open-loop ground source heat pump systems: a case study

Paolo Conti[1], Marco Pellegrini[2], Gioia Falcone[3]

[1] University of Pisa - DESTEC, Largo Lucio Lazzarino, 56122, Pisa (IT)

[2] University of Bologna - DIN, Via Fontanelle 40, 47121, Forlì (IT)

[3] University of Glasgow, University Avenue, G12 8QQ, Glasgow (UK)

paolo.conti@unipi.it

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ABSTRACT

This paper presents the application of the United Nations Framework Classification for Resources (UNFC) to an open-loop ground source heat pump (GSHP) in Italy. The UNFC is a universal classification system aimed at facilitating the comparison and the decision-making process for all the stakeholders involved in a specific energy project.

The classification object is the expected geothermal energy use following Project development. In this case, we deal with the replacement of some methane boilers in the office buildings of an electric transformation station with three reversible open-loop heat pumps (nominal capacity, 3x70 kW_{th}) and one open-loop chiller (nominal capacity, 55 kW_{th}).

The paper provides a general view of the UNFC application, showing the classification steps the information needed to complete the classification of a groundwater heat pump system, according to a "scenario" approach. The final Project classification at the date of evaluation (2018) is "Commercial Project, approved for development". The geothermal Resource is 6.7, 11.6, 13.8 PJ in thirty years as low, best, and high estimate, respectively.

The paper highlights the general applicability of the UNFC scheme and the benefits in terms of reporting the Project energy production in a consistent perspective including technical, economic, social, environmental elements, together with uncertainties and risks assessment.

1. INTRODUCTION

The development of geothermal energy is not related only to technical subjects (i.e. engineering and geology). In recent years, many works and research projects have dealt with the effects of non-technical features, such as social acceptance, policy, regulatory, and economic frameworks, as well as the relationships with financial stakeholders. In this framework, the lack of a plain universal framework to define, report and communicate about geothermal energy is slowing down the geothermal development at a global scale, in favour of other renewable or non-renewable energy sources.

The decision about planning and funding of any energy infrastructure (included the geothermal one) involves many heterogeneous subjects and competencies: governments, field owners, industrial operators, investors, development banks and aid agencies, reserves auditors, insurance companies, international energy associations, agencies and councils. Among many other elements, a common universal-adopted terminology and a classification system is thus necessary to rank possible energy alternatives, according to the needs of all involved stakeholders.

The question of standardizing the assessment of the geothermal potential (in a general sense) is not new: there have been several attempts to provide a universal classification scheme using different criteria. The definition of commonly-used terms as "geothermal energy", "geothermal resource", "geothermal potential" has been widely discussed and reviewed in scientific reviews and reports. The most popular past and present classification approaches refer to (Falcone et al., 2013, Falcone and Beardsmore, 2015):

- Accessibility and Discovery;
- Level of Temperature, Use, Type and Status;
- Technical, economic, sustainable, developable "Potential";
- Exergy;
- Geological Confidence and "Modifying Factors".

Together with different classification criteria, many heterogeneous classification classes are currently used: e.g., resources, reserves, inferred, economical, uneconomical, and others. Shortly, a universal terminology and classification approach has never been established: each of mentioned classification systems has drawbacks and limitations, leaving the door open for ambiguity and subjectivity (Falcone, 2015, Falcone and Beardsmore, 2015).

This is also due to an intrinsic limit of the geothermal energy, as it refers to a very large number of multidisciplinary subjects (geology, geophysics, mining and wells sciences, thermal and electrical engineering), geological contexts, exploitation and conversion technologies (power plants, wells, thermal engineering), different regulatory, social, and environmental contexts around the world. Additionally, we mention the need for defining a common framework or a bridging logic for other energy sources.

In this perspective and with such ambitious goals, the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) is intended to be a universally acceptable and internationally applicable scheme for the classification and reporting energy sources, including renewables and geothermal ones (ECE, 2013). It captures the common principles and provides a tool for consistent reporting energy extraction and conversion process, regardless of the energy source. The classification target moves from the characterization of what is available in nature to the actual topic of interest for the stakeholders, namely to provide indicators on the feasibility, viability, risk, and sustainability of the energy exploitation. In other words, the classification scheme does not classify and compare energy sources, but it deals with actual and well-defined energy conversion project, during a well-defined operational period, in a well-defined context. Details on the classification procedures are shortly presented in Section 2. The UNFC-2009 is also attractive for its generality and possible application to all energy sources, such as hydrocarbons and minerals. It has already been aligned with worldwide established classification protocols as the CRIRSCO Template and the PRMS (ECE, 2013).

The document “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” (hereafter *geospec*) was released in 2016, in the framework of a MoU signed between UNECE and IGA (Falcone et al., 2016). It includes the “rules of application” of the UNFC to Geothermal Energy Resources, and it is intended to be used in conjunction with the general UNFC documents and the specifications for the application of UNFC-2009 to renewable energy resources (Charpentier et al. 2016). Besides, a set of 14 case studies from Australia, Germany, Hungary, Iceland, Italy, Netherlands, New Zealand, Philippines and Russian Federation is been issued to facilitate the understanding of the specifications and how to apply the UNFC scheme to various geothermal resources and technologies, such as hydrothermal systems, EGS, direct uses, and heat pumps (Falcone et al. 2017). Currently, an ad-hoc sub-committee of the IGA resources and reserves committee is dedicated at promoting, testing and keeping updated the geothermal specifications.

In this paper, we present the application of the UNFC to an Aquifer Thermal Energy Storage system (ATES) to analyse benefits, possible limits, and rooms of improvement of current *geospec* regarding this technology. We show how UNFC classification helps the communication and the understandings of the actual level of favourability of energy projects, in terms of energy efficiency, viability, risk and uncertainties, permitting and environmental sustainability.

2. UNFC CLASSIFICATION SCHEME: PRINCIPLES AND DEFINITIONS

The UNFC classification scheme introduces some relevant features in the classification scheme to ensure the consistency of the classified quantities and the coherence/comparability among different cases. Classical energy classification schemes (e.g., McKelvey diagram) focuses on the characterization of the energy source, evaluating the level of exploitability in a general technical and economical perspective. UNFC introduces some innovative elements to better define the actual advantages and the risk in a well-defined project-related context. The object of the classification moves from the classical “energy source” to the very specific energy conversion project and related expected energy product. In other words, UNFC does not aim only at reporting the characteristic of the energy source as it is in nature, but it refers to the very specific project and its capability to transform that source in a useful/marketable energy product in a precise technical, economic, legal, social, political, and environmental context. A Geothermal Energy Product is *“... an energy commodity that is saleable in an established market*” (Falcone et al., 2016). Typical Geothermal Energy Products are electricity and heat, but also other secondary compounds can be included in the evaluation. In that perspective, the resource is not the total amount of the geothermal energy potentially convertible in a marketable product, but it is the actual cumulative quantities of the Geothermal Energy Products that will be extracted from the Source by the Project in a defined period (Falcone et al., 2016).

The Project is the core of the classification procedure, as it represents the between the Geothermal Energy Source and quantities of Geothermal Energy Products. Its definition includes scopes, a defined activity (or set of activities), the maturity and the implementation level of the technical apparatus at the moment of the evaluation. Project definition also provides the basis for estimating both costs and potential revenues (economic evaluation) and decision-making.

The classification procedure and project definition are based on a consistent scientific and thermodynamics background. Even with a simplified approach, concepts as control volume, system boundary, energy fluxes are clearly identifiable in the procedure (see, for example, Table X). This is functional to the correct understandings of the conversion efficiency, mass and energy fluxes. The so-called Reference Points is one of the main elements of the classification procedures: it consists of a specified point in the Project layout at which declared quantities are measured or estimated. It does not have a fixed position and it can be placed at any location of the extraction, processing, or sales operations. Once defined, it is the unique and clear reference to "locate" the classified energy quantities in the overall energy conversion process. If a project produces multiple energy products, there may be different reference points for each product stream.

The classified quantity is energy, not power. In fact, the classification procedure does not refer to a nominal/theoretical operating condition, but it requires the description of the timespan over which the quantities are referred. In a general sense, it goes "... from the Effective Date of the evaluation forward till the end of the Project Lifetime/Limit". Further specifications can be found in (Falcone et al., 2016)

The uncertainty level of presented quantities (and the general Project) is declared, explained and classified according to three possible methodologies, including both probabilistic and deterministic approaches (ECE, 2013, Charpentier et al. 2016, Falcone et al., 2016). Uncertainty analysis is a fundamental step of the UNFC classification to ensure a proper decision on the part of stakeholders about project feasibility, viability and risk (in any sense).

2.1 The three-dimensional classification system, categories and classes.

The energy quantities/figures are classified according to three fundamental criteria/categories (named E, F and G), which are combined in a three-dimensional system, as shown in Figure 1. Each project has a mark on each of the three axes/categories and sub-categories with a numerical mark from 1 to 4. The combination of the three marks (namely, categories and sub-categories) gives the final class and sub-class of the project (see Figures2 and 3).

The first set of categories (the E axis) designates the degree of favourability of social and economic conditions in establishing the commercial viability of the project, including consideration of market prices and relevant legal, regulatory, environmental and contractual conditions. The lowest rating is at the origin of the axis and the most favoured at the top. Specific guidelines on social and environmental considerations have been issued and are available (Elliott, 2018a, Elliott, 2018b).

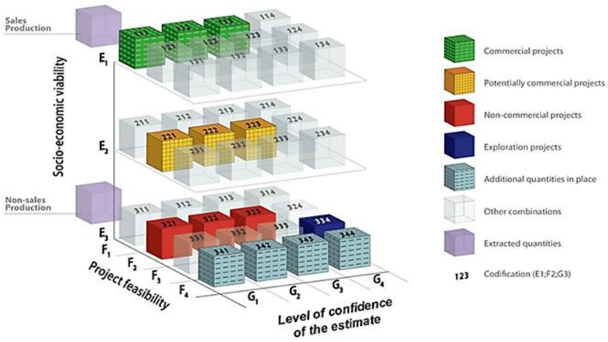

Figure 1: UNFC categories and examples of classes.

The second set (the F axis) designates the maturity of studies and commitments necessary to implement the project projects. It is not related to the technology maturity or to technical difficulties in a general sense, but it evaluates the progress of the project concept, design, authorization, funding, development, or operation. The valuation on the F axis discloses if the project is at the early exploration phase (before a deposit or accumulation has been confirmed to exist), till the running period when the project is already operating and selling an energy commodity. Shortly, the F axis aims at making stakeholders aware of the actual level of project development in a managing perspective.

The third set of categories (the G axis) designates the level of confidence in the presented figures, including the geological assessment and potential recoverability of the quantities. The G axis is intended to reflect all significant uncertainties impacting the estimated quantities (i.e. the resources) that are forecast to be extracted by the Project. Typical uncentres for geothermal energy system include geology (the source), energy conversion efficiency (the plant), economic and regulatory context, thermal demand to be met (direct system). We stress that uncertainties include also all variability in the energy source, energy loads, efficiency of the extraction and conversion processes, social, economic, and environmental operating context.

There are three methods to estimate G-axis value including both deterministic and probabilistic approaches, named "incremental", "scenario", and "probabilistic". Details on the three methods can be found in (ECE, 2013, Charpentier et al. 2016, Falcone et al., 2016). As a general concept, three different project outcome quantities are evaluated: the as low, best and the high estimate and characterized by a high, moderate, and low level of confidence, respectively. For instance, in the "probabilistic" approach, the three estimates named as "low estimate" (P90), "best estimate" (P50) and "high estimate" (P10) indicate the 90%, 50% and 10% of probability of exceeding the declared quantity, respectively.

Total Commodity Initially in Place	Extracted	Sales Production			
		Non-Sales Production[a]			
		Class	Categories		
			E	F	G[b]
	Future recovery by commercial development projects or mining operations	Commercial Projects[c]	1	1	1, 2, 3
	Potential future recovery by contingent development projects or mining operations	Potentially Commercial Projects[d]	2[e]	2	1, 2, 3
		Non-Commercial Projects[f]	3	2	1, 2, 3
	Additional quantities in place associated with known deposits[g]		3	4	1, 2, 3
	Potential future recovery by successful exploration activities	Exploration Projects	3	3	4
	Additional quantities in place associated with potential deposits[g]		3	4	4

Figure 2: UNFC categories and examples of classes.

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

Figure 3: UNFC-2009 Classes and Sub-classes defined by Sub-categories

3. CASE STUDY

ATES is a technology with a worldwide potential to provide sustainable space heating and cooling by (seasonally) storage and recovery of heat in the subsurface (Gao et al., 2017; Bloemendal et al., 2015; Lee, 2010). Adoption of ATES varies strongly across Europe, which is on the one hand due to differences in climatic and subsurface conditions, but on the other, due to local barriers for implementation of ATES. The E-USE(aq) innovation project (Pellegrini et al., 2019), financially supported by the European Institute of Innovation and Technology and by the Climate KIC in the frame of the Sustainable Land-Use theme, started on June 1st 2015 and has brought together nine partners (in particular, University of Bologna, Nomisma Energia and ASTER for Italy). The project objectives include the realization of six different ATES pilot plants in the following countries: The Netherlands (Delft and Utrecht), Spain (Nules), Italy (Bologna), Belgium (Ham) and Denmark (Birkerod). Different sites have been identified for the installation of an open-loop ground source heat pump (GSHP) system in Italy, and after a preliminary techno-economic analysis (Bianchini et al., 2017) the Martignone electric station, near Bologna, was identified as the most suitable site.

3.1 Current plant and description of the Project.

The ATES pilot plant is located in the electric station of Martignone, owned by Terna, which is the Italian operator in electricity transmission grids. The electric station of Martignone is a transformation station 380 kV/132 kV. Moreover, the station includes two buildings, one (letter A in Figure 4) hosting the emergency teams that cover the ordinary and extraordinary maintenance of 2,800 km of electric lines and the other one (letter B in Figure 4) hosting offices and remote control station. The heating and cooling plants of buildings A and B are not integrated.

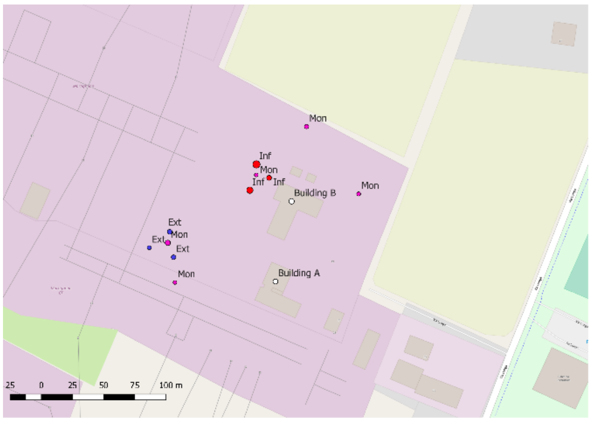

Figure 4: Wells positioning in the Italian pilot plant. Inf= infiltration wells, Ext= extraction wells, Mon = monitoring wells.

The A building, which is named “changing room building”, is a single floor building which includes a kitchen, two changing rooms, two shower rooms, three bathrooms and one tooling. The conditioned rooms have a volume of about 1,600 m^3 and are currently heated and cooled by a complex series of plants: a methane boiler (nominal capacity 103.5 kW_{th}), two reversible heat pumps (nominal heating capacity: 10 kW_{th}, nominal cooling capacity: 9 kW_{th}); four electric splits for air cooling, three iron cast radiators, four radiant ceiling panels; six 100 lt electric boilers for the production of domestic hot water.

The B building, which is named “office building”, is a two-floor building which includes several offices, four bathrooms, three data centres, one battery room, one remote control station. The conditioned rooms have a volume of about 3,800 m^3 and are currently heated and cooled by the following plants: one methane boiler (nominal capacity: 109.7 kW_{th}), one water-to-air chiller (nominal cooling capacity: 162 kW_{th}), four 50 lt electric boilers for the production of domestic hot water. All conditioned rooms are equipped with fan coils and are fed by a methane boiler and liquid-air chiller, except for data centre rooms, which are only cooled.

The energy Project to be classified consists of the installation of three reversible open-loop heat pumps (two in building B, one in building A, each one of about 70 kW_{th}), and one open-loop chiller with a nominal cooling capacity of about 55 kW_{th} in building B. The Project delivers thermal energy to buildings A and B, including also some data centre rooms in building B which need cooling all over the year. Hot water for heating purpose is produced up to 65 °C, while cold water for cooling is produced at 7 °C. The new system substitutes the existing methane boilers in buildings A and B and realizes a centralized cooling system for building A. The new plant is integrated by the existing water-to-air chiller installed in building B, and with two electric boilers of 57 kW_{th} each (one for each building), which are used as back-up unit of the ATES system for space heating. Heat exchange with groundwater is provided through plate exchangers and three couples of extraction-injection wells.

3.3 Energy audits: buildings demand and current system performances.

The peak requirements of heating and cooling power were estimated as in Table 1 to correctly design the open-loop GSHP. Heating peak has been computed accordingly to EN 12831:2003 by the software EdilClima. The external design temperature was fixed at -5 °C, while the conditioned rooms temperature was set at 20 °C. Cooling peak was estimated accordingly to the Carrier-Pizzotti method through the software EdilClima. The design has been done by considering an external air temperature of 33 °C, while the temperature of the conditioned room was set at 24 °C. One interesting result is that cooling peak demand is higher than heating one, and that it is concentrated in the office building. Then, according to the monthly-average climate data, an estimation of annual energy needs for heating and cooling has been carried out, accordingly to UNI EN ISO 13790:2008 and UNI/TS 11300-1:2014. The results are the buildings energy demand of 170 MWh/yr for heating and of 49 MWh/yr for cooling.

Due to the oversizing of existing methane boilers, a seasonal efficiency of about 80% has been attributed to the existing plants, considering heat generation, distribution, regulation and emission. The methane consumption has been estimated to be about 25,000 Nm^3/year. The latter value has been compared with the billing data of the year 2013, showing an optimal agreement (24,160 Nm^3). The computation of past electric energy consumption found different technical obstacles. First, there is no separated computation of electric energy consumption, i.e., there is one electric energy meter for the whole Martignone station. The presence of one meter is justified by the fact that Terna has a special contract for energy consumption, so there was no need to measure the consumption of different subsystems fed by electric energy in the station. Moreover, the larger quantity of electricity is consumed by the electric station itself, and not by the buildings' facilities, so there is no chance to make a seasonal analysis of the whole electric consumption to identify summertime consumption due to air conditioners. However, following the data in Table 1 and assuming a seasonal energy efficiency ratio of 3.0, the electricity needed by the existing water-to-air chillers can be estimated in 16,300 kWh.

Table 1: Estimated peak and buildings energy demand for heating and cooling.

Building A	**Heating**		**Cooling**	
	Peak [kW]	**Energy [MWh/y]**	**Peak [kW]**	**Energy [MWh/y]**
Tooling	16.8	20.0	0.0	0.0
Changing room	11.8	14.0	13.1	4.0
Other rooms	28.3	33.0	2.7	1.0
Total A	*56.9*	*67.0*	*15.8*	*5.0*
Building B	**Heating**		**Cooling**	
	Peak [kW]	**Energy [MWh/y]**	**Peak [kW]**	**Energy [MWh/y]**
Ground floor	43.1	51.0	68.7	22.0
Second floor	44.7	52.0	71.2	22.0
Total B	*87.8*	*103.0*	*139.9*	*44.0*
TOTAL (A+B)	**144.7**	**170.0**	**155.7**	**49.0**

3.4 Characterization and evaluation of the geothermal/renewable source and possible environmental issues.

Preliminary pumping test started on 19th September 2016 and was completed on 31st October 2016. Test was carried on a 100 meters' depth and 4'' diameter well through: a submersible centrifugal pump with a vertical axis, a water volumetric flowrate meter, and a phreatimeter used to measure the variation of the water level. The preliminary pumping test was realized accordingly to EN ISO 22282-4.

The results of the pumping test (Bianchini et al., 2017) showed that the maximum water flow rate that can be extracted from one well has to be set at 1.8 l/s (6,5 m^3/h), otherwise the groundwater level in the well would drop dramatically. During a following constant rate test at 1.8 l/s, two nearby wells were used as monitoring wells. The lowering of the aquifer was in the order of centimetres. It was also noted that the aquifer has very quick recharging, since, after the pump was stopped, in less than two minutes the level turns into the starting value. Since the flowrate potential extraction from one well is limited, the minimum number of wells to guarantee the satisfaction of the peak thermal demand must be identified. Regional permit allows a maximum temperature variation of injected groundwater of 5 °C, and so, by considering the peak demand (see Table 1), the minimum number of extraction wells results equal to three.

Further pumping tests were organized between October 2017 and February 2018 to verify the behaviour of the aquifer in conditions similar to the peak demand operating ones (i.e. three pumps extracting the maximum groundwater flowrate from the three extraction wells and injecting it back in the three injection wells). The test completed on 2017 and 2018 substantially confirmed the preliminary test results.

The use of tracer dyes is a technically valid and cost-effective method for characterizing contaminant fluxes and hydraulic properties in complex hydrogeological systems. In Terna site this method has been applied to have relevant information about water flow direction within the groundwater during pumping test at a variable flow rate and with the maximum flow rate allowed. A test has been realized with contemporary water extraction from the three extraction wells and water re-injection in the three injection wells. The evaluation of water flow direction allows to better evaluate the thermal short-circuit risk. No international standards are available to determine how the test should be carried on. The test has been arranged as follows: a concentration of about 200 g/l of Sodium-Chloride (NaCl) has been induced in one injection well – the nearest one to extraction wells. Then, the three pumps installed in the three extraction wells started pumping at maximum flow rate. A three days continuous monitoring has been completed: a conductivity variation has been observed only in the nearest injection/extraction well-couple, so it was concluded that thermal short-circuit risk should be very low.

Finally, chemical-physical characteristics of the groundwater were assessed to verify if the aquifer contains some pollutants and to evaluate the clogging potential of wells. The results of groundwater samples analysis in 2016 showed a high manganese concentration. After a brief literature survey, it was found that high concentration of manganese and/or iron is quite common in the area and it is not of anthropogenic origin. Further samples have been taken from the three extraction wells during the last pumping test in 2017 and 2018. In particular, two different tests were performed: redox potential, measurement of manganese concentration in the sample and in the filtered portion of the sample (0.45 micron filter), to estimate the percentage of manganese presence in colloidal form. Since the manganese is quite completely unfiltered, it means that there is a negligible fraction of not dissolved manganese, and so manganese is present mainly in colloidal form, which is a good result since clogging problems due to manganese precipitation in the injection wells should be avoided.

3.5 Product type and reference point(s)

The classified energy quantity, i.e. the Resource, consists of thermal energy exchanged with the ground source, namely the "extracted" geothermal energy. According to Falcone et al., 2016 and Falcone et al., 2017, the classification of a GSHP Project requires the presentation of the overall system energy balance and associated energy quantities in four main points (see Figure 5): the energy exchanged with the ground source (point A), the thermal output of the heat pump unit (point B), the driven energy (point C), and the total heat delivered to the end-user system (point D).

In this assessment, point A is chosen as Reference Point to report and classify the Geothermal Energy Resources according to UNFC-2009. For the sake of clarity, all the main energy quantities related to the project operation are summarized in Table 2. Since the pilot plant can be operated also in reversible mode (i.e. cooling), also the energy "injected" in the ground source is considered: in this case, the ground works as a heat sink more than an heat source. This issue represents one of the limit of the UNFC classification.

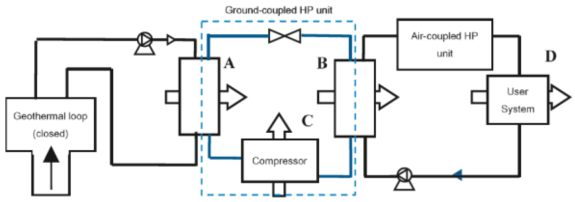

Figure 5: Schematic representation of the energy fluxes and evaluation points in a groundwater heat pump system (heating mode).

3.6 The "scenario" approach: expected energy quantities and project lifetime.

According to UNFC (ECE, 2013), the degree of uncertainty associated with the energy estimates must be always reported and discussed. The so-called "scenario" approach consists of generating three future production profiles named low, best and high estimates. A low estimate scenario is directly equivalent to a high confidence estimate (i.e. G1), whereas the best estimate scenario is equivalent to the combination of the high confidence and moderate confidence estimates (G1+G2). A high estimate scenario is equivalent to the combination of high, moderate and low confidence estimates (G1+G2+G3). Additionally, we recall that the three scenarios can be associated to the same principles of estimates derived from a probability analysis: the quantities associated to the low, best, and high estimate scenarios reflect the probability of 90%, 50%, and 10% to be exceeded during the actual operation, respectively (Charpentier et al., 2016).

- *Low estimate.* In this scenario, ATES system is assumed to deliver the 70% of both heating and cooling demands for 30 years (i.e., project lifetime). This scenario is very unlikely, as the nominal water flow rate, about 3.8 l/s, is lower than the proven sustainable exploitation of the aquifer (5.4 l/s, see Section 3.4), which is anyway able to satisfy a peak demand. Additionally, both the three reversible heat pumps and the chiller are oversized with respect to the heating and cooling demands. The oversizing is justified by the specific nature of the site: an electrical station which needs high requirements in terms of operation guarantee, especially for the data processing center. Due to these requirements, great part of the plant components was oversized or redundant. Therefore, a 70% of load coverage, can be justified only in case of unexpected serious system failures or forced stops. For example, if long term impact on groundwater temperature is produced by the plant, the regional authority may decide to retire the authorization for groundwater extraction/injection. This case is remote, also because groundwater temperature will be monitored to evaluate the seasonal impact of heating and cooling extraction from the aquifer, and so countermeasures can be quickly adopted. However, assuming an average 2 °C temperature increase/decrease of the extracted groundwater for cooling/heating purpose over the project lifetime, the mean seasonal COP and EER would be 3.7 and 8.0, respectively. Electric boilers efficiency is estimated in 90%, while water-to-air chiller seasonal EER is fixed at 3.0. The combination of these two efficiencies and the assumed load ratio between the GSHP and back-up generators lead to a yearly electric energy consumption of about 98.1 MWh (88.9 MWh for heating and 9.2 MWh for cooling, see Table 2).

- *Best estimate.* In this scenario the ATES system meets the 85% of heating and cooling demand, while the remaining 15% is supplied by back-up units (electric boilers and water-to-air chiller). The reduced working hours can be caused by the clogging of the injection wells (i.e. manganese precipitation, see Section 3.4), reduced groundwater extraction capacity (i.e. water scarcity in summertime), or components failure. Moreover, a negative impact of thermal short-circuit between extraction and injection wells is accounted: in the case of an average 1 °C increasing/decreasing of the extracted groundwater temperature during the project lifetime (i.e., 30 years), the mean seasonal COP and EER would be 3.9 and 8.3, respectively. The result is a yearly electric energy consumption that can be estimated in about 72.9 MWh (65.4 MWh for heating and 7.5 MWh for cooling, see Table 2).

- *High estimate.* In the best scenario, groundwater heat pumps are assumed to work with a seasonal COP of about 4.0, while the seasonal EER of the chillers have been estimated in about 8.5. The system is considered as able to satisfy 100% of heating and cooling demands (justified by plant oversizing aforementioned) and no relevant thermal short-circuit occurs between extraction and injection wells (justified by preliminary test, see section 3.4). The EER value is very high if compared with water-to-air chiller since in summertime the air can reach temperatures up to 35-40°C, while groundwater is more or less constant under 20°C. Shortly, for the assumed 30-year lifetime, yearly electric energy consumption can be estimated in about 48.3 MWh (42.5 MWh for heating and 5.8 MWh for cooling). The energy fluxes are summarized in Table 2.

Table 2. Energy fluxes in MWh/year for the three scenarios analysed. Letters A, B, C refer to Figure 5.

Scenario	Operation	Energy exchange with the aquifer (A)	Energy delivered to the user system (B)	Electricity input to the GSHPs (C)	Energy delivered by the back-up units	Electricity input to the back-up units	Total electricity consumption
High	Heating	127.5	170.0	42.5	0	0	42.5
	Cooling	43.3	49.0	5.8	0	0	5.8
Best	Heating	107.4	144.5	37.1	25.5	28.3	65.4
	Cooling	37.0	42.0	5.0	7	2.5	7.5
Low	Heating	86.8	119	32.2	51.0	56.7	88.9
	Cooling	30.0	34.3	4.3	14.7	4.9	9.2

4. UNFC CLASSIFICATION

The final classification for the Project is shown in Table 3. The geothermal Resource to be classified is the heat extracted by the ground source in the reference point A. The final class and sub-class are “Commercial Project, approved for development”.

The assigned classification depends on the economic evaluation that is the most critical element among the features list considered in the E-axis (see the decision trees in Falcone et al. 2016). The project has favourable legal. regulatory, market access, social, political, and authorization conditions. All the required permits, such as water extraction and injection, have been released.

The environmental assessment shows a significant reduction up to 11.7 tons of oil equivalent (TOE) and of 35.8 tons of equivalent CO_2 emissions with respect to a traditional boiler/chiller. There is no air, water, soil pollution or material disposal associated to the project operation. Table 4 shows the economic figures of the investment as a function of the scenarios: the investment cost (including design, preliminary tests, authorization process) is rather high and the annual savings achievable are not able to make the investment very attractive, since the payback time is quite long (12 – 14 years) in all the three scenarios.

Table 3. Final classification (reference time: 30 years, Reference point A*:).

Classification based on UNFC classes	Classified energy quantity(ies)	Supplemental information
E1.2; F1.2; G1	9.3 TJ (86.8 MWh/y)	- Nominal capacity of the GSHP system: 210/265 kW_{th} heating/cooling; - Expected seasonal COP/EER: 3.7/8.0. - Assumed Project lifetime: 30 years. - Ground-coupled apparatus deliver about 75% of both building and cooling load.
E1.2; F1.2; G1+G2	11,6 TJ (107.4 MWh/y)	- Nominal capacity of the GSHP system: 210/265 kW_{th} heating/cooling; - Expected seasonal COP/EER: 3.9/8.3. - Assumed Project lifetime: 30 years. Ground-coupled apparatus deliver about 85% of both building and cooling load
E1.2; F1.2; G1+G2 + G3	13.8 PJ (127.5 MWh/y)	- Nominal capacity of the GSHP system: 210/265 kWth heating/cooling; - Expected seasonal COP/EER: 4.0/8.5. - Assumed Project lifetime: 30 years. - Ground-coupled apparatus deliver about 100% of both building and cooling load
Project Location: Bologna, Italy **Date:** 2018 **Date of evaluation:** 2018 **Quantification method:** simulation and well-testing methods. **Estimate type (deterministic/probabilistic):** deterministic scenario.		

4.1 E category classification and subclassification

Category	UNFC definition	Brief reasoning for classification
E.1	Extraction and sale have been confirmed to be economically viable	The high investment cost and the long payback period (longer than 10 years) may result not attractive for investors. The payback period can be shortened if subsidies are considered.
E1.2	Extraction and sale are not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.	

The high investment cost relates to the specific nature of the site: an electrical substation with high standard requirements regarding operation continuity. Due to these requirements, great part of the construction works is redundant to ensure constant energy production back-up. The resulting higher investment costs affect the economic figures. The high investment is also influenced by the complex monitoring system to measure with high accuracy both the thermal plant performance and the impact of the pilot on the groundwater. Furthermore, the investment includes the retrofitting of existing distributing pipelines and heat/cold terminals and the preliminary tests carried on for the characterization of the aquifer, which may be not necessary in similar installations.

Table 4. Main figures of the project economic assessment (reference time: 30 years).

Category	Amount without subsidies		
	High scenario	**Best scenario**	**Low scenario**
Investment	460 k€	460 k€	460 k€
Discount rate	4%	4%	4%
NPV	520 k€	480 k€	408 k€
Payback time	12 years	12 years	14 years
	Amount with subsidies		
	High scenario	**Best scenario**	**Low scenario**
Investment	460 k€	460 k€	460 k€
Discount rate	4%	4%	4%
NPV	618 k€	570 k€	472 k€
Payback time	8 years	9 years	11 years

The investment becomes more attractive if subsidies are considered: payback period is shortened to 8 years in the high scenario due to about 70.000€ of the whole investment that can be fiscally deduced in ten years, plus the benefits coming from white certificates selling. On the other hand, Table 4 highlights the relatively low impact of electric energy bills increasing from high to low scenario: this is a specific condition of the site, that has very low electric energy costs.

4.2 F category classification and subclassification

Category	UNFC definition	Reasoning for classification
F.1	Feasibility of extraction by a defined development project or mining operation has been confirmed	All the preliminary studies and analysis are completed, as well as the Project design and CAPEX commitment.
F.1.2	Capital funds have been committed and implementation of the development project or mining operation is underway.	

The project design, together with the environmental and economic assessment, have been completed: the construction operations are about to start as soon as final authorizations will be received from local authorities.. All the capital funds have been committed.

4.3 G category classification and subclassification

Category	UNFC definition	Reasoning for classification
G1	Quantities associated with a known deposit that can be estimated with a high level of confidence.	*Low-estimate* See section 3.6
G2	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.	*Best-estimate* See section 3.6
G3	Quantities associated with a known deposit that can be estimated with a low level of confidence.	*High-estimate* See section 3.6

5. CONCLUSIONS

This paper presented the application of the United Nations Framework Classification for Resources (UNFC) to an open-loop ground source heat pump (GSHP) in Italy. The classified Project concerned the replacement of the methane boilers in two service buildings in a 380kV/132kV electric transformation station. The new thermal generators are three reversible open-loop heat pumps (3x70 kW_{th}) and one open-loop chiller (55 kW_{th}).

The final Project classification at the date of evaluation is “Commercial Project, approved for development”. The geothermal Resource is 9.3, 11.6, 13.8 PJ in thirty years for the low, best, and high estimate, respectively.

The paper provided a general view of the UNFC application, showing the all the steps needed to complete the classification: definition of the Project within a greater and complex energy system, the description of the product type (i.e., the Resource), the reference point, and project lifetime. The description included both source experimental characterization and thermal load evaluation, together with a clear assessment of the energy conversion performances.

The paper showed the general applicability of the UNFC scheme in a complex energy system made of integrated generators and different energy technologies. The final UNFC class and subclass clearly summarize all technical, environmental, social, regulatory, economy features, helping the understanding of the actual level of development of the project, expected energy and economical performances, and associated uncertainties.

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