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A basic screening for the development of CO_2 Capture and Storage in the Italian power sector

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***Abstract*— Recent studies by the IEA (International Energy Agency) and EIA (Energy Information Administration) estimate that global energy consumption will increase by 28% between 2015 and 2040, with fossil fuels still providing the bulk, some 77%, of energy consumption. While it is unequivocal that we are in a period of energy transition to a world without fossil fuels in both energy and industry, this transition is too slow compared to the speed of anthropogenic pollution-induced climate change that is affecting our planet. With countries such as China, USA, India, Poland and Germany still firmly dependent on coal to meet their energy needs, it is clear that further delay in implementing technologies such as CCS (Carbon Capture and Storage), which can intervene directly on power stations without having to close them down and then replace them with renewable plants, would be a serious mistake. The objective of this preliminary screening analysis is to identify potential sites on the Italian territory suitable for geological storage of CO_2, in order to lay the foundations for conversion projects using Carbon Capture and Storage technology in Italian thermoelectric power plants. The introductory phase will be dedicated to the description of CCS technology, highlighting its importance in limiting emissions for climate protection; this will be followed by a description of the context in which the analysis is carried out. The next phase will be related to the description of the scientific model used that allowed the realisation of a database of the most favourable sites for CO_2 injection in the Italian subsoil. The results will be reported according to the thermoelectric plant(s) considered. The final part of the work will include an objective analysis of the results obtained as well as a description of possible future developments.**

Keywords—Carbon Capture and Storage; caprock; CO_2 storage; power plant.

I. INTRODUCTION (*Heading 1*)

Following the impulse controlled by the European Directive No.2009/31/EC the main Italian energy and industrial companies such as Enel, Edison, Repower (formerly Rezia Energia), Carbosulcis, SARAS refineries, have started to show more and more interest in CCS technology (Carbon Capture and Storage) as a way to find a solution to the increasingly stringent regulations on CO_2 emissions regarding the production of electricity from fossil sources or the refining of hydrocarbons, cement plants and steel mills.

If in those years (early 2010) this interest was justified by a curiosity towards a still semi-unknown technology, today this interest has become a priority because of the rapid acceleration of climate change largely influenced by the increase in greenhouse gas emissions into the atmosphere, especially the CO_2 that reached 411 ppm.[1] This growth is mainly attributable to the increase in the world's population which combined with the increase in welfare and industrial growth (in the ET (Evolving Transistion) scenario, the GDP growth is expected to be around 3,25% per year, substantially in line with the growth recorded in the last 25 years) has led to an increase in global primary energy demand with a trend that shows no sign of decreasing. [2]

So far global climate models didn't achieve satisfactory results from economic and environmental point of view, considering the goals set with the Paris Agreement in 2015. One of the reasons appears to be the lack of consideration of strategic technologies such as CCS, bioenergy and their combination, in favor of slow renewable technologies and energy efficiency.

The gap between the global efforts currently underway, directed almost only towards a slow technological choice linked to RES (Renewable Energy Sources) and energy efficiency, characterized by a very low energy density with the same GHGs (GreenHouse Gasses) avoided in the atmosphere (we must consider that a lot of publications on these technologies systematically omit the space / time variables in the reduction of greenhouse gases for the same energy produced as well as the space to install the MW) and the emission reductions necessary to reach the 2 ° C target agreed in Paris is immense. It would require around 760 giga-tonnes (Gt) of CO_2 emissions reduction across the energy sector between now and 2060. [3]

Although no CCS plant has been opened in our country, many studies have been done on it, some of which have been financed by the European Community such as the ENEL projects for the conversion of the Portotolle and Brindisi coal-fired power plants. [4] These projects were not carried out for reasons linked more to economical than technical aspects, such as the lack of a single Carbon Tax which actually makes CO_2 a new currency (CO_2-coin) in order to give equal incentives to all technologies (incentives now actually offered only to RES technologies and energy efficiency). CCS technology, however, has made important progress in the field of research over the last ten years with the aim of reducing electricity production costs, and reduce the emission's gap with modern gas combined cycle plants. The natural gas plants, although unequivocally cleaner than their coal "cousins", still have a greenhouse gas emission rate (GHGs) of about 350 g CO_2 / kWh, a value that may no longer fall within the future regulations emissions limits [5]. In this regard, the European Investment Bank (EIB) has decided to block the financing of the fossil projects without systems to reduce polluting emissions and has set a new standard for the emissions of eligible projects (Emission Performance Standard) , equal to 250 grams of CO_2 per kWh (previously: 550 g CO_2 / kWh) from 2022. [6]

It is therefore clear that we are increasingly moving towards the "decarbonisation" of industrial plants, a context in which CCS technology has and will have an important role as a technology capable of rehabilitating fossil fuels plants no longer compliant, thanks to post-combustion CO_2 capture technology which has demonstrated to be able to accomplish reduction rates higher than 90%. [7]

The purpose of this research is the identification of potential sites suitable for the geological storage of CO_2 on the Italian territory, based on the first pilot studies, thus forming the basis for retrofitting projects of Italian thermoelectric power plants and large energy-using plants through the use of capture and carbon storage technology. It was therefore decided to examine a group of 16 thermoelectric power plants, considered as data sets of potential CO_2 sources, so as to embrace a large part of the Italian territory. The examined plants are all powered by natural gas, with the exception of that of San Filippo del Mela. Some of these, such as the former coal-fired power plant of Brindisi [8] as well as that of Turbigo, have undergone a modernization with a retrofit from coal to natural gas. The fight against climate change has in fact led Italy as well as many other countries in the world to adopt policies aimed at decarbonising their energy sectors. One of the most evident aspects of that policy is the progressive closure of coal plants in many European countries. With reference to the Italian context, the national energy strategy launched in 2017 has the objective of closing all coal plants by 2025. [9] With a fossil energy sector soon powered only by natural gas in many countries of the world and with the emission limits gradually decreasing, the objectives of research and development on CCS have also expanded, embracing not only coal-fired plants but also those powered by natural gas.

II. METHODS

A. CO_2 sources

The thermoelectric power plants taken into consideration are shown in table 1 while their geolocation is shown in fig. 1.

TABLE I : THERMAL POWER PLANTS INVOLVED IN THE STUDY

Power plant	Company	Address	Maximum power (MW)/tons CO_2 emitted (ktons/year)
Brindisi	A2A S.p.A.	Brindisi	148 (/) [8]
S. Filippo del Mela	A2A S.p.A.	S. Filippo del Mela (ME)	640 (688,9) [10]
Candela	Edison S.p.A.	Candela (FG)	360 (520,8) [11]
Simeri Crichi	Edison S.p.A.	Simeri Crichi (CZ)	857 (1417,5) [12]
Altomonte	Edison S.p.A.	Altomonte (CS)	780 (1399,9) [13]
Torviscosa	Edison S.p.A.	Torviscosa (UD)	790 (1399) [14]
Marghera	Edison S.p.A.	Porto Marghera (VE)	766 (849) [15]
Bussi	Edison S.p.A.	Bussi (PE)	124 (44,3) [16]
Jesi	Edison S.p.A.	Jesi(AN)	130 (/) [17]
Turbigo	Iren S.p.A.	Turbigo (MI)	855 (482) [18]
Sermide	A2A S.p.A.	Sermide (MN)	1154 (556,2) [19]
Chivasso	A2A S.p.A.	Chivasso (TO)	1179 (865,7) [20]
Piacenza	A2A S.p.A.	Piacenza	855 (642,8) [21]
Porto Viro	Edison S.p.A.	Porto Viro (RO)	125 (/) [17]
Sarmato	Edison S.p.A.	Sarmato (PC)	180 (/) [17]
San Quirico	Edison S.p.A.	San Quirico Trecasali (PR)	125 (/) [17]

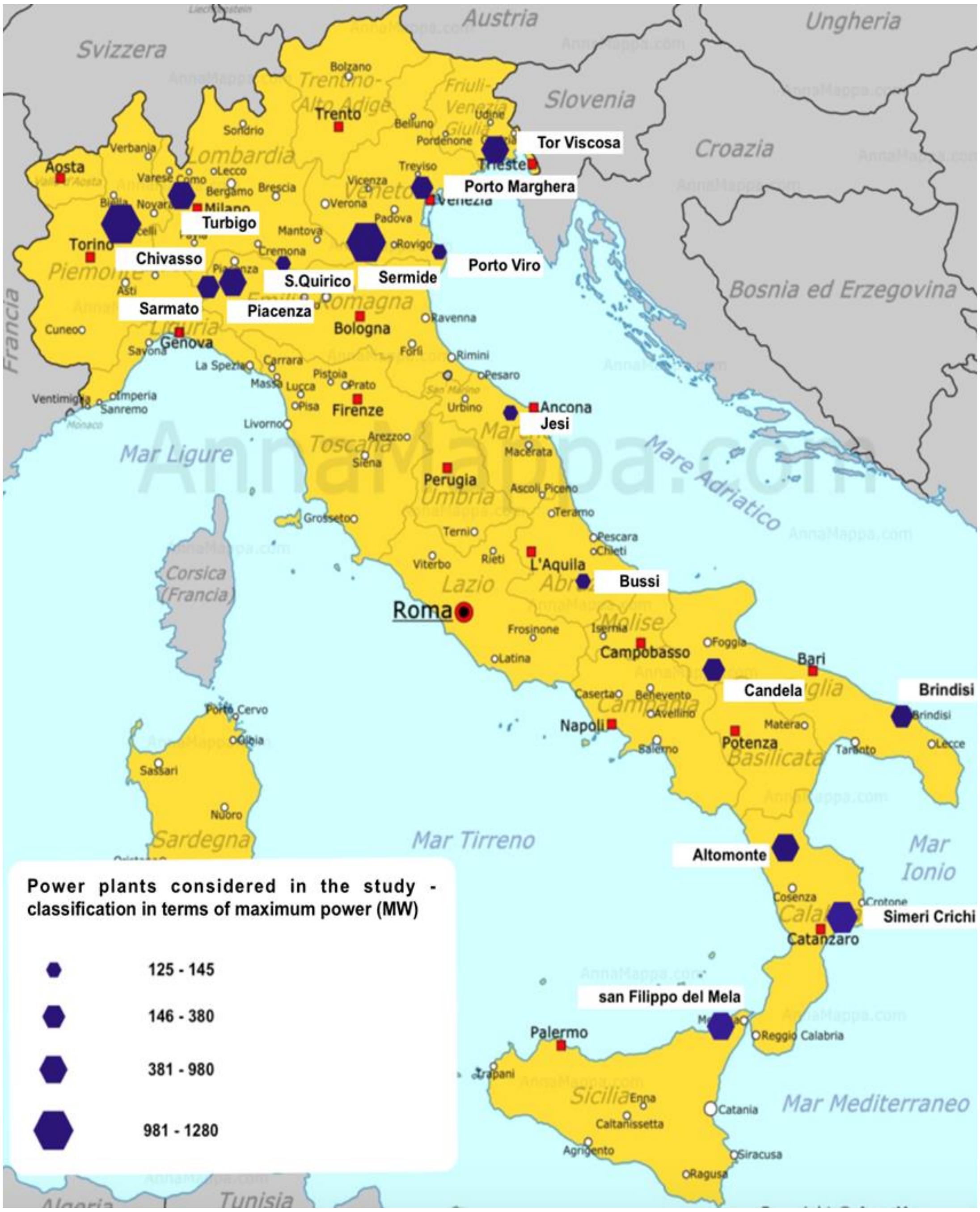

Fig 1: geolocalization of the thermal power plants considered in the study. For each of them it was decided to set a search buffer of 150 km. The power plants have been classified in function of their maximum power (source: https://annamappa.com/italia/mappa-italia.jpg).

B. Database of the subsoil potentially suitable for CO_2 storage

The territory around the aforementioned power plants has been analyzed for its geological aspect with the aim of identifying possible solutions regarding the storage of carbon dioxide produced by these power plants. The search for a potential geological CO_2 storage site must necessarily take into account, in addition to the good quality of the caprock, the presence of a deep saline aquifer (possibly closed by a spill point at the base of the structure, in which to inject) and the presence of a structure capable of containing CO_2, including all those risks that could in some way influence the containment capacity of the structure during and after the injection. Basically these risks are rappresented by the presence of potentially seismogenic or notoriously seismogenic structures and structures of potential degassing from peri-volcanic endogenous gas or natural gas up to ground water [22, 23, 24, 25, 26, 27, 28 ,29] The need to build pipelines [30, 31] for the transport of fluid from industrial CO_2 sources to CO_2 storage sites implies the search for sites that operate by source clusters [32], so as to significantly reduce transport costs via pipelines. We then analyzed the data obtained in an area of 150 km around the plants of interest. The analysis carried out on each site took into consideration the quality of the caprock and the possible presence of deep saline aquifers suitable for geological storage according to a methodology described by Buttinelli [33]. The data used for this analysis came from deep wells for industrial use in the 1960s and from seismic lines, aimed to explore the hydrocarbons in Italy from the 1950s and 1960s. The identification of potential CO_2 storage sites throughout Italy was carried out through the structuring of a catalog on the caprock's quality and

the presence of deep saline aquifers (the Well Quality Factor catalog from "Well good factor" [33] created by INGV, CESI Research and University of Rome 3 [34, 35]). This first attempt to build a catalog of CO_2 storage sites in Italy was experimented using data available from the database of the Ministry of Economic Development (UNMIG) relating to oil exploration drillings carried out from the 1950s up to today. The catalog was structured by INGV and partners (with the client CESI Ricerca S.p.A in 2006) [22, 33] by selecting from the database of wells available on the Italian territory (around 1700), wells with depths greater than 800 m (around 1300). This operation was necessary since the storage of CO_2 is feasible only at depths greater than 800 m (where the CO_2 is in the supercritical phase). It was therefore reasonable to consider only the subset of wells in which saline aquifers are located at depths greater than 800 m. The construction of the database on the caprock's quality and the presence of deep saline aquifers, identifies in a very effective way the situations that have a good and / or excellent caprock (i.e. strong thicknesses of impermeable lithologies over deep regional saline aquifers), but above all, it helps to understand how the waterproofing situation extends into a specific block and therefore in the examined areas. This is an excellent starting point to focus on an area looking for potential CO_2 injection structures as a cluster for multiple CO_2 sources.

The catalog was structured by processing the stratigraphic information from the composite logs, parameterizing the found lithologies as a function of their permeability and developing algorithms that relate the given lithological nature and its thickness. Then we calculated the WQF (Well Quality Factor) [22, 33], which numerically describes the quality of the caprock above a potential CO_2 injection aquifer, seen in each single well.

In particular, the process to define the WQF (Well Quality Factor), is composed of the following steps:

a. a general parameterization of the lithologies seen by all wells, according to their permeability. The classification was structured on the basis of a division of the classes according to a simple lithological estimate. The CLI (Class LItotipe) factor was therefore created (with values ranging from 1 to 5 according to the impermeability): from 1 for conglomerates and breccias up to 5 for clayey lithologies.
b. The LQF (Quality Factor of the i-th Lithotype, variable from 1 to 5) factor was created using the CLI parameter multiplied by the thickness of the lithology found (TLI = Thickness of LIthology), normalizing this product to an ideal thickness of impermeable lithology fixed at 800 m (TFS = Thickness For Storage), according to the formula:

$$LQF = (CLI * TLI) / TFS \qquad (1)$$

The application of the algorithm leads to the production of LQF values both higher than the maximum value (LQF = 5), and not whole but decimal values. For LQF values higher than the maximum value (produced by the presence of very impermeable lithologies, crossed in the well for high thicknesses) it was decided to define the LQF (downgrading it) with the maximum value (LQF = 5). This operation does not affect the validity of the application of the algorithm, since through this analysis we mainly want to discriminate unsuitable roofing situations (poorly impermeable or small thicknesses) from suitable ones (thickness of at least 800m of impermeable lithology to define an excellent coverage). For thicknesses greater than 800m of impermeable lithology, the excellent quality of the coverage is already achieved, therefore they can be considered with an LQF = 5. The decimal Fbi values produced through the algorithm were automatically rounded off during the creation phases to the nearest integer. This new parameter describes the propensity of a rock encountered in a well to behave as a more or less impermeable caprock for the storage of CO_2 (LQF 3-4-5) or from permeable reservoirs that will host CO_2 (LQF 1-2). The SPC (Thickness for Storage) parameter set at 800 m is due to the need to consider impermeable lithologies with a thickness greater than 800 m (and in absolute certainty of the presence of an excellent caprock). After this first processing, the database of the results of the well stratigraphy is not constituted by a real stratigraphy, but by a parametric stratigraphy, consisting of alternations of LQF, which highlight the caprock (series of lithologies with LQF values from 3 to 5) above permeable reservoirs (LQF 1 to 3). At this stage there is still no information on the presence or absence of saline aquifers, contained in lithologies with LQF 1 to 3.
c. The WQF parameter was therefore created, without the use of a specific algorithm (as done for the creation of the LQF), due to the high diversity of the geological-stratigraphic situations encountered throughout the Italian territory, during the analysis of the available well logs, which did not allow to establish a single criterion for its definition. The construction of this parameter was therefore addressed in a "case by case" mode, analyzing for each log of wells of the analysis data set the alternations of the LQF of the caprock lithologies, overlying the lithologies with the LQF that characterizes the tanks (where we have information on the presence of potential deep injection saline aquifers). To create this parameter

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it was necessary to consider as caprock, defined in a unique way, all the succession of rocks encountered above the rocks that are the site of a potential reservoir.

The range of values assumed by the WQF parameter is between 0 and 5, in order to describe the best hedging situations in ascending order.

The possible caprock-aquifer associations encountered are defined as follows:

a. WQF from 0 to 2. This range of values corresponds to 0 when there's an absence of coverage (or very shallow aquifer), while the values 1 and 2 represent situations with poor coverage on a shallow aquifer, or thick series of permeable lithologies (not suitable for CO_2 confinement) above deep aquifers.
b. For situations with less permeable caprocks above the potential CO_2 injection saline aquifers, WQF from 3 to 5 has been assigned. This range of WQF values corresponds to the alternations of WQF that characterize the succession of caprock (with more thicknesses or less high), from 400m up to thicknesses > 2000m) consisting of medium to very impermeable lithologies (marl, clay marl, clay-silt in lenses) above a potential saline aquifer useful for CO_2 injection. Coverage situations characterized by modest thicknesses (about 400 m) of impermeable lithologies above a potential aquifer placed at high depths (i.e. when the upper part of the caprock at depths greater than 800 m) have been also considered favorable.

The construction of a database on the caprock's quality and the presence of deep saline aquifers has had the merit of identifying in a very effective way the situations that present good and / or excellent caprock (i.e. strong thicknesses of impermeable lithologies over deep regional saline aquifers), but above all it helped to understand how the covering situation extends in a specific area under consideration (the thickening of good and excellent WQF situations indicates for example a wide distribution of good caprock and saline aquifers, very useful for assessing the storage potential of CO_2). This is an excellent starting point to focus the search for potential CO_2 injection structures in given area. On the other hand, however, the creation of the Well Quality Factor (WQF) tends to underestimate some situations potentially favorable to the storage of CO_2, creating low WQF values (as previously described). Similar situations occur only when sequences of rocks that are generally considered as caprock have been drilled, without reaching the deep reservoir, or when there are no explicit indications in the well log on the presence of a saline aquifer at high depths (there are no reports of saline aquifers where there should be or at the well are attached poor quality geophysical logs that do not allow to identify the presence of water).

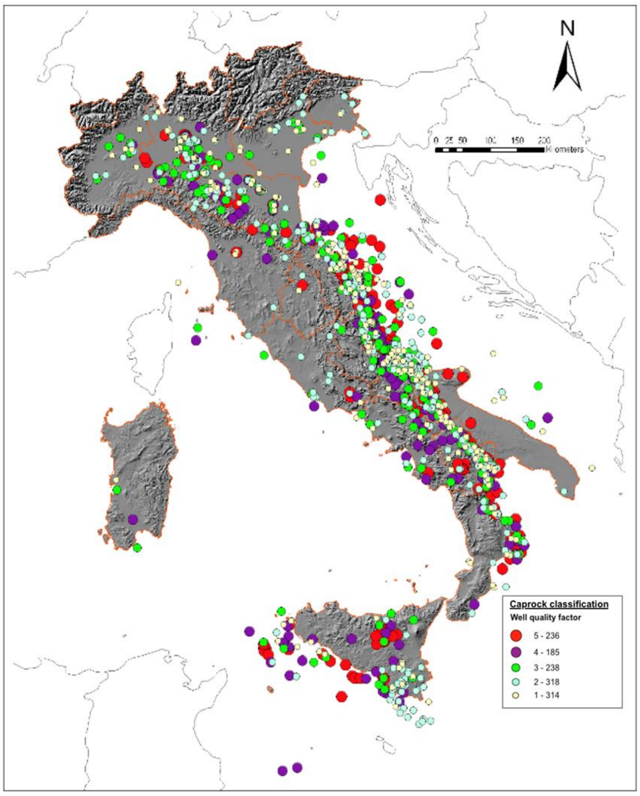

Fig 2: map with the projection of the geodatabase on the characterization of the quality of the caprock for the geological storage of CO_2 through the parameter WQF (Well Quality Factor), throughout Italy, produced by INGV - CESI Ricerca - Roma3. Modified from the INGV internal report "SELEZIONE SUL TERRITORIO ITALIANO DI ACQUIFERI SALINI IDONEI ALLO STOCCAGGIO GEOLOGICO DI CO_2 E LORO RISK ASSESSMENT"

It should be noted in these cases that the creation of the WQF tends to underestimate and downgrade some potential situations favorable to the geological storage of CO_2. There are therefore some (albeit not numerous) real situations on the Italian territory regarding the caprock-reservoir couple which are better than the projection of the database highlights.

The semi-automatic analysis of the catalog and the related critical review of the results obtained are a seismic lines and available structural maps, it is possible to identify potential traps for the geological storage of CO_2 and, subsequently, in a detailed work phase, it is possible to define the extent, volume and capacity of storage.

The results of processing the caprock's quality geodatabase are shown in Fig. 2. The Italian territory is characterized by a high seismicity, but is localized along particular structural alignments, linked to the

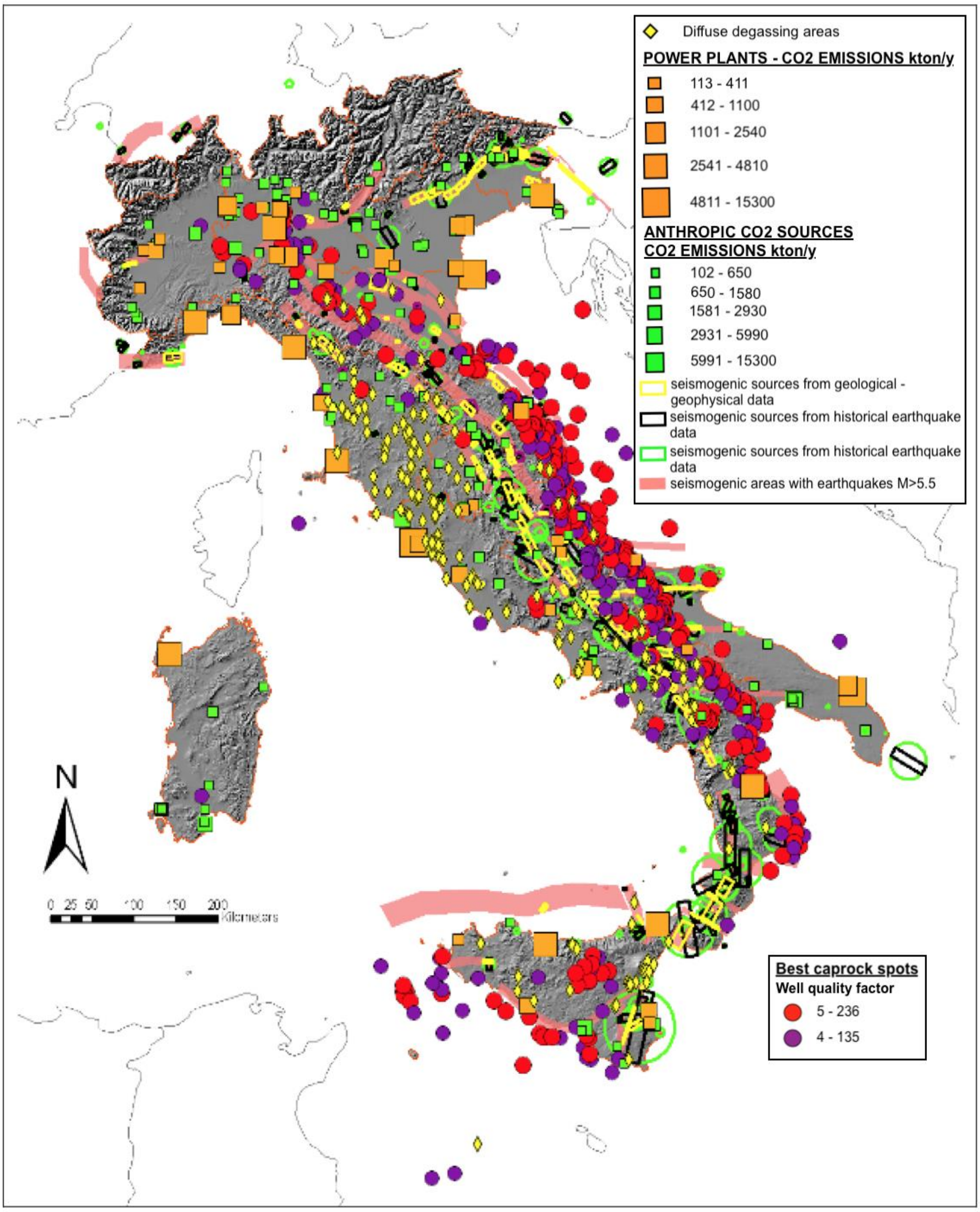

Fig 3: map of the distribution in Italy of the caprocks with good and excellent qualities (WQF 4 and 5) produced by INGV - CESI Ricerca - Roma 3. Connexion with the distribution of areas containing seismogenic structures (DISS 3.0.2.2 catalog produced by INGV). Modified from the INGV internal report "SELEZIONE SUL TERRITORIO ITALIANO DI ACQUIFERI SALINI IDONEI ALLO STOCCAGGIO GEOLOGICO DI CO_2 E LORO RISK ASSESSMENT

fundamental starting point for identifying potential CO_2 storage structures, where there is evidence of good coverage and the presence of saline aquifers (Fbp 4-5). By integrating this analysis with the review of presence of the Alpine-Apennine orogens. Considering the spatial distribution of potentially seismogenic structures, the nature and distribution of seismic events in association with the distribution of the quality of the caprock and the presence of saline aquifers, has allowed to focus the search for a potential storage site in not seismogenic area or low seismicity area, with favorable conditions of caprock and saline aquifers. For the search for potential CO_2 storage sites, the seismic catalogs (CPTI, DISS, ISIDE, WAVES, CSI, NTI) produced by INGV were considered. This made it possible to map the seismicity distribution on the Italian territory, considering the presence of active structures (faults) either in a seismogenic level as well as and from the point of view of the ascend of deep fluids (Geochemically Active Fault Zones [36] [40]) which have produced seismicity in the past [37]. Another geological risk that must necessarily be considered for the identification of potential carbon dioxide storage sites is the distribution of diffuse degassing structures (DDS). The presence of DDS in the area is evidence of a high state of fracture of the most superficial portion of the crust at that point, due to the presence of one or more discontinuity structures, such as fractures and / or patent faults. It is clear that in that area the caprock is naturally pervious. It is as if we had a CO_2 storage that was chosen without all the guarantees: an escape route. The fracturing state up to the gaseous reservoir could be the cause of the connection between the deep systems (where there are possibly saline aquifers in which CO_2 must be injected) and the earth's surface. These discontinuities (fractures and faults) could therefore constitute preferential ways to trace fluids from the depths, an effect that occurs naturally in these areas and must be avoided in the case of a project for the deep storage of CO_2. Very useful in this sense can be 3D modeling, inserting all the various georeferenced risk objects [38], using these pre-existing escape routes, as monitoring points with the use of tracers [39] to see the behavior of the gas in ascent, whether injected (traceable CO_2) or the natural one, if the overpressure had started in depth, thus allowing to analyze a possible connection between nearby structures.

The search for a potential CO_2 storage site must generally take into account the distance from a vast area of degassing.

In this sense, the distribution of DDS on the Italian territory (unpublished data INGV Quattrocchi, 2020) in association with the other risks already considered, of the nature of the caprock and the presence of saline aquifers, not already enriched in CO_2 (especially the Tyrrhenian side characterized by deep saline aquifers already saturated in CO_2) allowed the creation of the geodatabase shown in Fig. 3.

C. Source-storage connection

The search for a potential CO_2 storage site near the indicated power plants substantially followed the following steps, including the possible logistical paths of possible CO_2 pipelines [32]:

a) Full analysis of existing data in an area of respect generally set at 150 km radius from the plant examined ;
b) Identification and characterization, through risk analysis of public well data, of suitable caprocks, impermeable over suitable saline aquifers, volumetrically above 200 millions of tons of stored CO_2, locations of a potential CO_2 injection;
c) Check of the presence of structures for the confinement of CO_2 through the analysis of the public database of seismic reflection lines, possibly selecting structures with a defined and clear spill-point, keeping in mind the possible faults. The sub-set of the seismic lines that pass through the wells identified with good WQF was analyzed through the previous analysis that we have available (possibility of calibration, recognition of reflex horizons and discontinuities, in comparison with the logs of the wells present nearby, etc ...);
d) Check of the distance of the structure identified from potentially seismogenic areas, with historical and paleo-seismological evaluation of potential seismicity and the return time of strong earthquakes (e.g. 500 years / fault);
e) Verification of the distance of the structure identified from diffuse degassing structures (DDS);
f) Definition of potential areas in which to deepen the knowledge with detailed studies of the horizons of reflection (unconformities) of the reservoir and the caprock on the geometry and potential of the identified confinement structures.

III. RESULTS

The analysis conducted, considering the CO_2 sources of the thermoelectric plants with respect to the position of saline aquifers, with at least a WQF from 4 to 5, and analyzing the risk factors, faults, DDS, high historical seismicity in the DISS (Database of Individual Seismogenic Sources) catalog of Italian active faults (www.ingv.it), led to: i) a first identification of potentially suitable sites (complete CCS pilot projects), around the plants considered (in addition to any other large energy-intensive plants); ii) made it possible to identify about ninety potential areas, of which about seventy on-shore and more than twenty off-shore. Many of them have geological structures not sufficiently supported by data and not constrained enough on risk factors.

A. Northern Italy

For the thermoelectric power plants in this part of the work, the elaborations carried out on the stratigraphy of the wells and of the seismic sections are grouped, available for the area in question. The survey sector falls within a total area resulting from the overlapping of the polygons of the areas (buffers), with a radius of 150 km, around each plant in Northern Italy. Based on the data available in GIS catalog INGV (source: UNMIG) wells drilled in Italy in the field of investigation, are approximately 3200 (including 550 off-shore and on-shore about 2650), of which:

- About 550 with sufficiently detailed seismic profile available;

- about 1200 with existing profile;
- about 1500 with missing profile, of which it is difficult to even access the records.

Within the data set of available wells (561 already analyzed by Buttinelli [33]), 59 are off-shore and 502 on-shore according to that work. Of these surveys, those with Well Quality Factor (WQF) 3-4-5 were considered. Obviously the next work would be to analyze the structures three-dimensionally, in light of the recent progress of the concept of "containment" and "capacity" from 2005 to today. In particular, the off-shore geological structure of Cornelia in front of Pesaro is very interesting, as regards the Chivasso and Turbigo power plants.

It should be noted that this area of Northern Italy has the power plants of Sarmato, Piacenza, S. Quirico, Sermide, along the axis of the plicative compressive seismogenic structures that triggered with the 2012 seismic sequence in Emilia-Romagna [26, 27]. While Portoviro, Marghera and Tor Viscosa can refer more calmly to the offshore CO_2 storage sites already discussed for the aforementioned Porto Tolle ENEL-EEPR Project (Scientific Manager Fedora Quattrocchi, 2008-2011). Stratigraphy data, mining events, chemical analysis where present were extracted for the wells processed.

The analyzes carried out so far for the search for possible CO_2 storage sites in Northern Italy, mainly through the evaluation of the quality of the caprock, the presence of deep saline aquifers, the seismicity available, the relationship with seismicity and diffuse degassing systems, have led in recognition of 31 sites potentially suitable for geological storage of CO_2.

B. *Central – Southern Italy*

1) *Jesi thermal power plant*

The first step of the analysis regarding the search for potential carbon dioxide storage sites for the Jesi power plant took into consideration the information from the seismotectonic and structural stratigraphic data as well as the presence of offshore saline aquifers. As regards the stratigraphic data of the wells contained in the database made available by the Italian Ministry of Economic Development, in the buffer of 150 km of radius from the Jesi power plant, the geodatabase highlights the presence of:

- about 1700 georeferenced wells
- about 450 wells with readable composite log;
- about 300 wells with depths greater than 800 m, taken in consideration for the possible presence of caprocks suitable for trapping the CO_2

The characterization of the caprock and the presence of saline aquifers according to the production catalog INGV-CESI Ricerca - Roma Tre highlights for the area under examination the presence of a good quality of the caprock but of only about half sufficiently far from seismogenic sources (eg INGV DISS Catalog, eg 20 km distance):

- about 70 wells with excellent caprock (WQF 5)
- about 40 wells with good caprock (WQF 4)
- about 50 wells with medium coverage (WQF 3)
- 130 about 130 wells with medium to low to absent caprock (WQF from 2 to 0)
- about 40 wells with a saline aquifer often of adequate volume as shown in the relative composite log.

Therefore, only those wells with a good to excellent caprock quality were taken into consideration (WQF 4 and 5). The presence of potentially seismogenic structures in the vicinity of these selected wells is indispensable for discriminating between medium-low or no seismicity areas, away from structures (faults) potentially generating Jesi's type earthquakes (almost never absent in Italy with the exclusion perhaps only from Puglia region, where it is impossible to carry out CO_2 storage). For example, the area is totally located in the Apennine chain Foredeep, where there is the advantage of the almost total absence of CO_2-prevalent DDS, as in the INGV catalog. - DPCV5 project: "the Catalog of Italian Gas Emissions" (http://googas.ov.ingv.it/). In general, on the Italian territory, these are mainly located along the Tyrrhenian margin, while the Adriatic margin, (Foredeep) occasionally presents methane (natural gas) DDS, activated also according to seismicity.

Taking into account all these data, about fifteen possible CO_2 storage sites were identified, from an initial hypothesis of 20 sites. Obviously also in this case because of the proximity to the Adriatic coast, the Cornelia structure would be the first site considered.

2) *Bussi thermal power plant*

In the area of respect of 150 km of radius from the Bussi power plant, the geo-database highlights the presence of:

- about 1450 georeferenced wells;
- about 500 wells of which the geophysical log is available;
- about 450 wells with depths greater than 800m, suitable to be further evaluated for the goodness of the caprock in order to be exploited for CO_2 storage purposes.

In the sector analyzed, the Apennine orogeny has contributed to the formation of several deep anticlinical plicative structures, covered by a suitable caprock thickness, potentially interesting for the CO_2 storage, which were already over time the target of oil exploration (and therefore investigated through drilling and seismic surveys), both in the offshore and in the shore.

The characterization of the caprock and the presence of saline aquifers according to the production catalog INGV - CESI Ricerca - Roma Tre [22, 33] highlights the presence of:

- about 100 wells with optimal coverage (WQF 5)
- about 60 wells with good caprock (WQF 4)
- about 100 wells with medium caprock (WQF 3)
- about 200 wells with medium to low to absent caprock (WQF from 2 to 0)
- about 75 wells with an evident saline aquifer reported in the composite log

3) Candela thermal power plant

The area of interest around the Candela power plant crosses, starting from W going to E, the peri-Tyrrhenian margin, the southern Apennines and finally the Adriatic offshore.
In the survey sector, there are approximately 1350 drilled wells (source UNMIG), of which 75 offshore and 1250 onshore, of these:

- about 400 with seismic profile available;
- about 800 with existing seismic profile of mediocre quality;
- about 100 with missing seismic profile.

Within the approximately 400 wells available, (about 20 wells are off-shore and about 380 on-shore), the analysis was carried out on those having WQF 4 -5 (good to excellent caprock conditions), which presented, at least a saline aquifer and a distance of at least 10 km from seismogenic bands. The analyzes carried out so far to search for possible CO_2 storage sites in the 150 km buffer zone around the Candela power plant, (mainly carried out through: i) the evaluation of the quality of the caprock, ii) the presence of deep saline aquifers; iii) suitable structures, including faults - assessable in detail with the available seismic reflection -) led to the recognition of 26 sites potentially exploitable for the geological storage of CO_2.
It must bear in mind that the area is still to be subjected to the production of natural gas, therefore these are wells / sites to be explored only in the future. For the storage of CO_2 we should wait for a further depletion of the reservoirs so that the volume for CO_2 is available in structures well known at that point, both in terms of volumetric and well pressures, which can be reached. However, we are on the edge of an area of very low seismicity (Puglia).

4) Brindisi thermal power plant

In order to carry out a preliminary screening on the search for a potentially valid area for the storage of CO_2 produced by the Brindisi power plant (moreover near the pilot capture plant that was built by ENEL at that site) only the wells belonging to the Adriatic offshore between Bari and Brindisi were chosen. The main reason is that the Apulian hinterland can be considered in fact a "reservoir" with an open-air relative aquifer, and without a suitable caprock. The offshore wells are located at a reasonably low distance (max 150 km) from the possible CO_2 emitter, considering the need to build pipelines, possibly also submerged [1].
In the area of interest, there is a relatively high presence of deep drilling data in the UNMIG database.
The characterization of the caprock and the presence of saline aquifers according to the production catalog INGV-CESI Ricerca - Roma Tre [22, 33] highlights the presence of:

- about 20 wells with excellent caprock (WQF 5)
- about 10 wells with good caprock (WQF 4)
- about 20 wells with medium caprock (WQF 3)
- about 50 wells with medium to low to absent caprock (WQF 2 to 0)
- about 15 wells with an evident saline aquifer reported in the composite log

The Adriatic offshore area between Bari and Brindisi, at the edge of the area of respect of 150 km around the power plant, does not have large structures that can stored the amount of CO_2 produced for at least 20 years of life of the power plant.
An alternative could be to shift the attention to the Bradanica Pit (place of interest also for a project carried on by Rezia Energia (now Repower) in 2008 for the Saline Ioniche power plant). The Bradanic Pit in fact is characterized by very good caprock's quality and presence of very good deep saline aquifers (WQF 4 and 5 for many of the wells analyzed in the INGV geodatabase) [22, 33].
This alternative could also be considered in function of the construction of longer CO2 transport pipelines (around 200 km), built completely onshore, rather than offshore as would be necessary in the Adriatic area.

5) Altomonte thermal power plant

The Altomonte power plant is located within the search buffers of potential CO_2 storage sites relating to the Candela and Simeri-Crichi plants, as well as on the south-western edge of the Brindisi plant's research area.
These areas have already been analyzed, around the power plants of interest, both from a geological-structural point of view, as well as regarding the search for potential CO_2 storage structures. Falling back to the Altomonte power plant within these areas already studied, please refer to the descriptions and analyzes relating to the chapters of the Simeri-Crichi, Candela and Brindisi power plants.

6) Thermal power plants of Simeri-Crichi and San Filippo del Mela

The stratigraphies of the wells and seismic sections, available for the Calabrian and Sicilian areas, can be useful for the Simeri-Crichi and San Filippo del Mela plants. The study area falls within the 150 km radius buffers centered on each of the plants under study.
The overall extension of the overlapping buffers is approximately 110,000 km^2, and covers two distinct sectors in Calabria and Sicily both characterized by in-land and off-shore portions.
Based on the data available in the GIS INGV catalog (source UNMIG), the wells drilled on the Italian territory, in the survey sector [25], are around 560 (90 offshore and around 470 onshore), of which

- about 90 with profile available;
- about 90 with existing profile;
- about 400 with missing profile.

Within the available wells (about 90), about 30 wells are located off-shore and about 50 are located on-shore. Of these, the surveys with WQF 3-4-5 were consulted (caprock conditions from fair to excellent). To these wells must be added those located in the offshore area of Gela and Scicli, which despite being outside the buffer of 150 km from the S. Filippo del Mela power plant, had stratigraphic-structural conditions potentially favorable for storage.

IV. CONCLUSIONS

The analysis carried out has allowed to identify about a hundred wells falling in potential CO_2 storage areas scattered over most of the Italian territory, of which about seventy located on-shore and about 25 located off-shore, with suitable characteristics of caprock as well as the presence of a saline aquifer. In addition to that, the analysis shew suitable conditions linked to the risk factors: lack of significant Diffuse Degassing Structures, and seismogenic faults of moderate magnitude but well known and mapped with respect to possible CO_2 storage areas. Although Italy has an important seismic history, this data can only be encouraging in the development of gas storage technology, including the storage of CO_2 with CCS technology. The good results obtained by Japan (a tangible example is the Tomakomai project), demonstrate that CCS technology can also be applied in the most seismic countries in the world.

This approach constitutes the necessary preparatory screening phase for the search for possible CO_2 storage sites through detailed analysis of the well stratigraphies available for the localization and characterization of a CO_2 injection site.

The analysis carried out has been made as a combination between a geo-referenced geo-database with the various geological / geological-geophysical-geochemical risk layers. The main aspects considered are:

a. the quality of the caprock (WQF Well Quality Factor);
b. the presence of Diffuse Degassing Structures (DDS);
c. the presence of seismogenic faults and other types of faults due to the ascend of deep fluids (the so-called Geochemically Active Faults Zones, GAFZ [40]), as an escape route, for the CO_2 that may be stored.

This work however doesn't want to be a solution to the problem of the search for a potential CO_2 storage site but a necessary first step in solving the problem.

Although most existing CCS projects use storage associated with EOR-CO_2 (Enhanced Oil Recovery using CO_2), future implementation of the technology will increasingly require storage in deep saline aquifers, which have a wider geographical distribution and theoretical capacity greater than oil and gas fields in the exhaustion phase.

In order to encourage the development of CCS technology, it is of fundamental importance to inform the public about its convenience. A prejudicial response from the local community, because of the lack of information, can have a fatal impact on the project and leave a negative legacy that can influence future projects somewhere else. A strong brake on the development and expansion of CCS technology in the world is the consequence of the deficient and incorrect public awareness of the aforementioned technology.

In this context, this research assumes even greater importance as it set the basis for the continuation of research on geological storage in Italy as well as for a public awareness project of this technology in our country.

In a historical period like the one we are living now, characterized by an energy transition towards zero-impact technologies, in a context still heavily dependent on fossil fuels, it is clear that the efforts to facilitate the evolution of CCS "bridge" technology are extremely urgent, given that the efforts being made up to today - in terms of reducing the GHGs emissions are still too weak and too focused on renewable technologies and energy efficiency.

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