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Storage capacity evaluation for development of CO_2 infrastructure in the west Mediterranean

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Abstract

"Integrated infrastructure for CO_2 transport and storage in the West Mediterranean", known by the acronym COMET is an FP7 project, funded by the European Commssion. COMET Work Package 3 aims to identify and to evaluate geological structures and formations that have a potential to host CO_2 captured from industrial plants. Although these structures can be just defined through their location, geometry and capacity, there are many other factors that will have an influence in the behaviour of the storage, such as injectivity, salinity, sealing rocks, etc. Many of these factors are studied within COMET and their values are included in generated databases.

Moreover, COMET Project also aims to evaluate different scenarios of CO_2 sources and sinks in the West Mediterranean region, in order to propose most effective settings for CO_2 transport and storage networks. The goal of COMET is to use all available geological parameters in order to obtain a qualitative qualification of the storage sites. This qualification will be useful for network modellers who will use it as a tool to decide where most effective solutions can be found for linking CO_2 sources and sinks.

Moreover, once storage sites are identified, evaluated and ranked, a quantification of the potential storage costs has been carried out. These costs are used as a first approach to much more detailed models that are under development in other Work Packages.

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Keywords: Carbon dioxide; Geological storage; CO_2 storage capacity; Storage databases; Site Selection

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1. Introduction

Project COMET, aiming to identify and assess the most cost effective CO_2 transport and storage infrastructure able to serve the West Mediterranean region, required an accurate identification and evaluation of potential storage sites in Portugal, Spain and Morocco.

Information about storage capacity and potential injection sites allows other working groups to establish models for an integrated infrastructure of CO_2 transport network in the study region. Previous work regarding CO_2 geological storages was almost inexistent in Portugal and Morocco, while Spain had developed a regional evaluation approach through the GeoCapacity Project (1). Deep saline aquifers and depleted oil and gas fields were looked for. Such areas, suitable for CO_2 storage, have been identified and potential quantities to be stored assessed. COMET has generated first estimates in Portugal and Morocco while an update and more focused study has been done on Spain.

Moreover, COMET has carried out also economic analysis to determine costs of geological storage in the region and the influence of several parameters on these costs. In order to support this analysis, COMET partners created a simple methodology to evaluate the quality of selected storage sites, making available an easy comparison between them. All the information generated was supplied to GIS experts that created a GeoPortal linked to the COMET Project webpage, where this information is easily accessible. Finally, results from the identification of sites working group have been used in the generation of network models in the region of work.

2. Objectives

The main goal pursued by COMET partners regarding storage sites was to identify and evaluate these sites in the Iberian Peninsula and Morocco. To fulfill this goal, several tasks were planned and performed. Each of these tasks also had a set of objectives that had to be covered during the project, in order to obtain a robust database to support later modelling works.

Task 1: Definition of criteria for site selection and methodology for calculation of storage capacity. In this task, the main objectives were to establish a unique and common methodology for site selection that can be applied at the same level by project participants in each participant country and to develop homogeneous calculation methodologies making available an integrated analysis of storages in three participant countries.

Task 2: Identification of potential storage sites in Portugal and Morocco and update in Spain. In this case, the main objective was the application of methodologies described in the previous task, leading to the quantification of some key parameters identified.

Task 3: Theoretical storage capacity calculation of the identified potential storage sites. The objective is to apply calculation methodologies developed in the first task using the values of parameters obtained during works of Task 2, in order to determine storage capacity at a local, national and regional scales.

Task 4: Generation of a database with relevant parameters to facilitate GIS works. In this case, the objective was to collect a complete set of relevant geographical, geological, technical and economic parameters to be used by future project models. This database would be specifically created for COMET although based in those created within the GeoCapacity Project (6th Framework Programme)

3. Description of work

3.1. Definition of criteria

To establish a common methodology for site selection that could be applied to the three participant countries, COMET got base on the experience of BRGM and IGME that had been partners in the previous GeoCapacity (2) and GESTCO (3) Projects funded by the EU in previous Framework Programmes. In this sense, partners defined the data that was needed for future works of storage capacity calculation and ranking qualification of sites, including also some other parameters that would be needed for future modelling works. Roughly, it was decided that criteria for site selection would mainly be based in the storage capacity and injectivity forecasted for the site and the existence of a sealing formation that would prevent CO_2 from coming back to the atmosphere.

On the other hand, it was also necessary to develop homogeneous calculation methodologies to use values of parameters obtained during the screening. COMET methodology is based on those generated and published by CSLF (4) and GeoCapacity (2) project, including different methodologies for hydrocarbon fields and saline aquifers. Coal seams were not taken in account because of the low capacity expected and, therefore, a lack of relevance in future models.

As a result of this work, a report on Site Selection Criteria (Fig.1) was issued and is publicly available. This report was used by project partners to obtain the homogeneous evaluation of storage sites in the region of work.


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Project COMET

Integrated infrastructure for CO_2 transport and storage in the west Mediterranean

Site Selection Criteria

D 3.1

These documents are based on the work developed under GESTCO and GeoCapacity Projects, where BRGM and IGME have been partners. These projects had also the goal to standardize methodologies for future projects. COMET will seek storage possibilities in deep saline aquifers and hydrocarbon deposits.

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Fig.1. Front page of the report on Site Selection Criteria developed to facilitate collection of databases (Le Nindre et al, 2010)

3.2. Identification of storage sites and theoretical calculation of their capacity

Following recommendations of the Site Selection Criteria Report (5), a detailed study of the potentially interesting areas in Spain, Portugal and Morocco was carried out. As stated before, the objectives of the work included the quantification of relevant parameters and the calculation of storage capacities, but, in order to facilitate an easier visualization of results, it was also decided to plot the boundaries of interesting areas, including storage structures and surrounding aquifers.

Although this is a regional work and results have been modelled taking in account sources, networks and sinks in the three countries, we will now introduce the identification of sinks work in a country by country basis. This way it will be more comprehensive in a geological point of view, taking also in account that the starting point for the work was different in Spain, Portugal and Morocco.

Portugal:

The capacity assessment focused on deep saline aquifers, since there are no exploited oil and gas fields and coal seams exist in a very restricted area. The storage capacity in those saline aquifers is estimated in the range of 3.8 to 7.6 Gt of CO_2, enough to store more than 100 years of the current national CO_2 emissions.

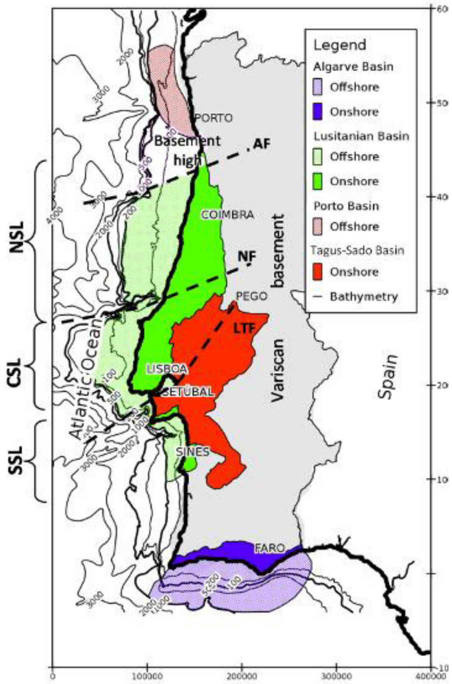


Fig.2. Schematic representation of the main sedimentary basins with a potentiality for CO_2 storage in Portugal (Carneiro et al, 2011)

Sedimentary basins occur along the coastal regions and extend to a vast offshore area (Fig.2). In particular, three offshore basins were targeted which account for about 95% of the total storage capacity in Portugal:

• *The Porto Basin* with a total area of 2150 km^2, located entirely offshore in the NW of the country. Target formations for storage purposes are located in Upper Triassic (Silves) and Lower Cretaceous (Torres Vedras) Sandstones. It has an estimated storage capacity of 1.0-2.1 Gt CO_2. This is a transboundary basin, extending to the Spanish Galicia basin.

• T*he Lusitanian basin*, with a total area of 22000 km^2, occurs both onshore and offshore, along most of the western coast of the country. Two sectors of the basin have been considered interesting (North Lusitanian and Sines), although a lack of information is reported in the second one. Target formations are the same defined in the Porto basin and estimated storage capacity ranges between 1.9 and 3.9 Gt CO_2.

• T*he Algarve basin*, occurring both onshore and offshore along the Southern coast of the country, with a total area of 8500 km^2. The potential storage formations are Upper Cretaceous sandstones and limestones and Miocene sands. It has to be stated that the water column over the marine soil are much higher in this basin than in the other ones. The estimated storage capacity is 0.7 to 1.3 Gt CO_2. This transboundary basin continues into Spanish territory where it is designated as the Gulf of Cádiz basin which was evaluated together with other offshore opportunities in Spain.

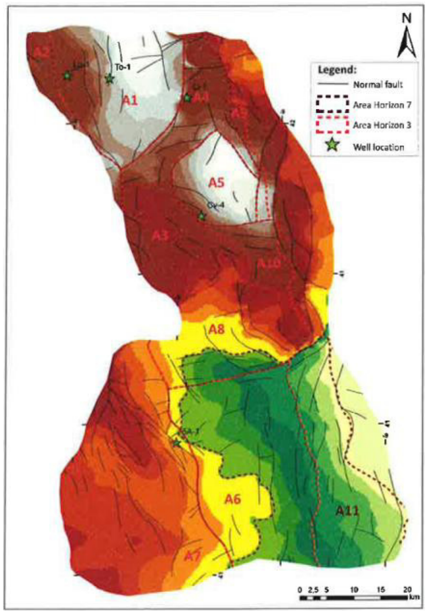


Fig.3. Depth representation of the Torres Vedras Formation in the Porto Basin, including fractures (Carneiro et al, 2011)

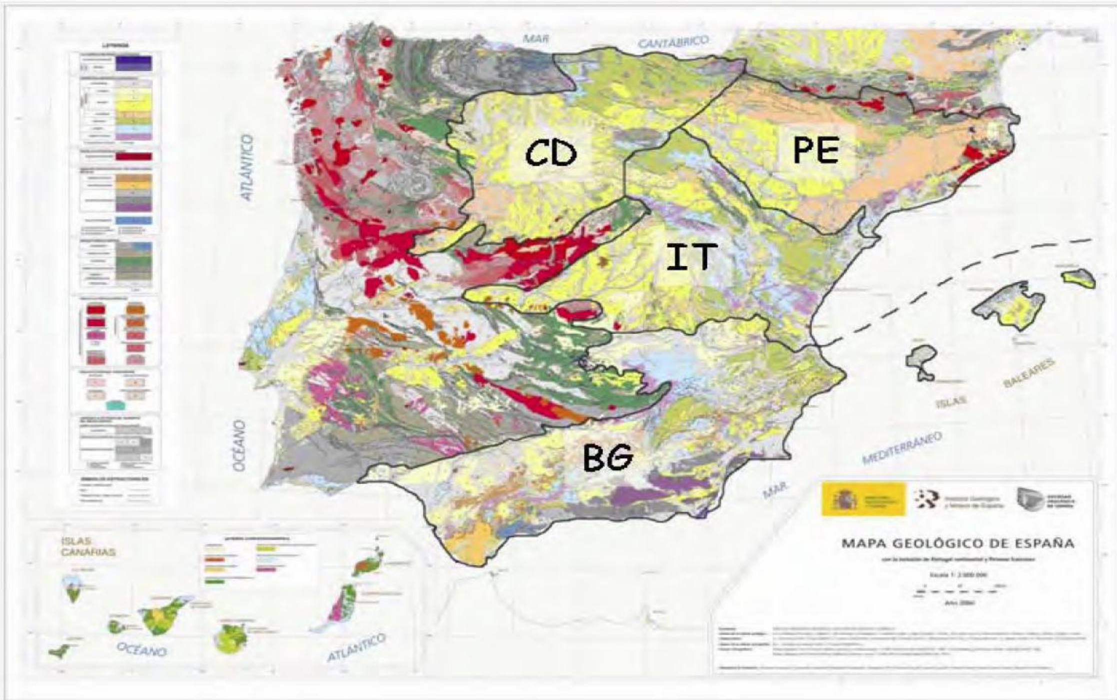
Onshore storage opportunities, limited to around 0.2–0.3 Gt CO_2, are located close to a large number of stationary sources and could prove of strategic importance for pilot project initiatives or industrial scale demonstration of CCS in Portugal.

Relevant issues identified in Portugal, to be addressed in further studies, is the highly faulted and folded nature of the reservoirs, and the proximity to active seismic regions. In this sense, it has been useful to create several structural and geological models at a basin scale (Fig.3). These models have made possible to structure the analysis in sectors, leading to a more realistic evaluation and calculation of capacities.

Spain:

The potential CO_2 storage in Spain is estimated between 17 and 28 Gt CO_2. This estimate takes into account transboundary areas of the Gulf of Cádiz and the Alborán Sea. Contrary to the situation in Portugal, a large share of the capacity is found onshore, particularly in the Eastern and Central part of the country, while the Western part is mostly inadequate. Offshore, some interesting areas are along the Cantabrian, Atlantic and Mediterranean coasts.

Onshore, there are four big sedimentary basins and other four interesting areas in mountain ranges (6) (Fig.4). These are:



- *Duero-Almazán Basin.* Located along the Spanish course of the Duero River, most interesting formations are found in the Cretaceous, with very porous sandstones and thick carbonated rocks. In this study, this basin potential has been complemented by some structures contained in the Cantabrian Mountain Range, mostly in the Eastern areas. The potential storage capacity of these areas ranges between 5.7 and 8 Gt of CO_2 and the main studies for pilot and demonstration projects in Spain are taking place in some of their more favourable formations.
- *Ebro Basin.* It covers the North East part of Spain and has a wide variety of potential storage formations, from Lower Triassic to Miocene, both in sandstones and carbonated rocks. The Ebro basin potential was studied together with the Spanish areas of the Pyrenees, although most of the total potential of 3.6 to 5.2 Gt is located in the Southern part of the basin (Fig.5).
- *Guadalquivir Basin.* It is a thin sedimentary basin located in the South of Spain, following the Northern border of the Baethic Mountains, which are also included in this study. Most interesting formations for CO_2 storage are Lower Triassic sandstones and Miocene sands. Some small hydrocarbon deposits are located in the area, leading to a large (compared to other locations in Spain) exploration of the subsurface, both through geophysical campaigns and borehole drilling (7). This basin continues under the sea in the Gulf of Cádiz, and to the Portuguese Algarve basin.

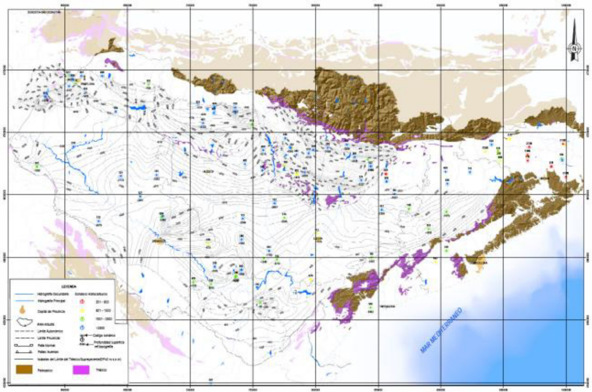
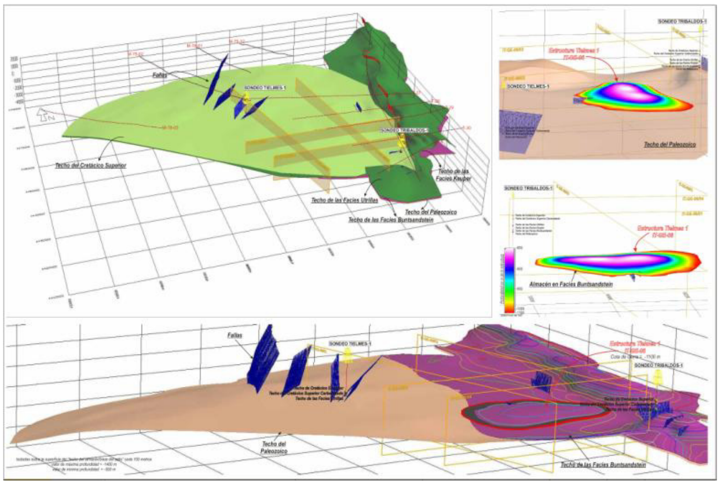


Fig.4 […] otentiality for carbon dioxide geological storag[…] of the lack of storage interest (García Lobón et al, 2011)

Fig.5 Depth map of the Buntsandstein sandstones in the Ebro River Basin (Pueyo et al, 2011)

- *Madrid-Tajo Basin.* Located in a wide plane to the South of Madrid, it is divided in two parts: Madrid Basin in the West and Intermediate Depression in the East. The Eastern part structure is better known because of oil exploration in the last century. Buntsandstein is the most promising formation in the East and the Cretaceous Utrillas sandstone in the West. This last formation is not taken in account in the Intermediate Depression because of low salinity. In this study, this basin has



been combined with the Iberian Mountain Range, where Mesozoic formations have a large potentiality.

Due to the previous works that had been carried out in Spain, the compilation of the subsurface information was much wider and, therefore, some more detailed studies could be developed in several areas. For a better calculation of the storage capacities, it was possible in many cases to use geological models at a structure scale (Fig.6), leading to more precise calculations and reducing uncertainties.

Fig.6 Static geological model of the Tielmes structure in the Madrid Basin (Olmedo et al, 2011)

In the offshore of Spain the previous work was not developed and COMET is the first systematic work evaluating offshore capacities for geological storage of CO_2 in Spain. 10 locations were included in this study, 4 in the Cantabrian Sea, 2 in the Atlantic Ocean and 4 in the Mediterranean Sea. Locations of Galicia and Gulf of Cádiz in the Atlantic are shared with Portugal and the Alborán Sea location in the Mediterranean is shared with Morocco and could lead to a more extensive cooperation in the future. Capacity in these areas is estimated ca. 1 Gt of carbon dioxide although total offshore capacity could be much higher in case a complete screening could be developed.

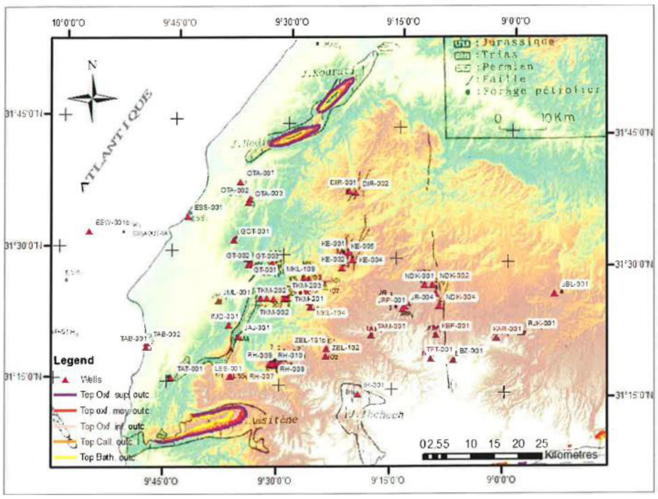
Morocco:

The CO_2 storage potential in Morocco relies on depleted oil and gas fields and neighbouring deep saline aquifers. Morocco has a limited amount of coal seams but they are located at shallow depths making them unsuitable for CO_2 storage. Only onshore potential was estimated. The preliminary estimates indicate an onshore potential storage capacity of 569 Mt CO_2, in the following basins:

Table 1 Summary of the Moroccan basins studied in the preliminary stages of COMET (Zahrloule and Rimi, 2011)

Basin	**Mediterranean**	**Gharb**	**Essaouira**	**Abda-Doukkala**	**Souss**
Type	Back arc	Foreland	Rift	Tiasic rift	Rift
Surface (Km²)	16000	7394	11858	11682	
Used Wells/Total wells	0 /2	2/53	12/44	2/11	0/9
Bedrock	Messinian	Miocene sup Cretaceous	Silurian and Jurassic black clay	Silurian and Devonian clay	Aptian-Albian clay
Reservoir	Miocene Sand	Turbditic sand	Triassic sand	Devonian Recif	Sand of Trias and Dogger Lias, sand and carbonate of Cretaceous
Seal	Miopliocene Clay		Salt of Trias and Malm anhydrites	Devonian clays, Liasic and Triasic salt, Marl of Jurasic Cretaceous	Anhydritic Carbonate

The resulting sink inventory is based on data compiled by Moroccan Office of Hydrocarbon and Mining (ONHYM), which consist on 20 oil and gas fields and 12 deep saline aquifers. There are totally onshore sinks, since the most part of the off shore wells are still properties of petroleum companies. The Essaouira (westernmost High Atlas, Fig.7) and the Gharb basin (Rif), are thought to be the most promising onshore regions, however the Garb



trap remain small and geologically complex.

In this sense, the geological information available due to oil and gas exploration and production have permitted a very detailed approach to these areas, including static modeling and gridding for capacity calculations. This very detailed approach has made possible the comparison between different storage capacity calculation methodologies and the study of the sensitiveness of final results to different storage efficiency factors. It could be concluded that, for the same area, the difference between a bulk capacity approach and the structural approach was in the margin of 10%, using low storage efficiency factors. In the next table, one of the calculations for Essaouira Basin is presented:

Table 2 Storage capacity calculations for the Essaouira Basin (Le Nindre, 2011)

Fig.7. Scheme of the areas and wells evaluated by COMET at the Essaouira Basin (Zahrloule et al, 2011)

Storage capacity of structures			
Well_name	***Pore_vol_Mm3***	***Rho_CO 2 Kg/m3***	***Storage_(***
GT-2	239	672	
KE-5	210	719	
DIR-1	173	775	
BZ-1	48	718	
MKL-101	35	905	
RH-8	29	696	
MKL-103	5	900	
ZEL-101 bis	3	889	
Total	**741**		

Some possible areas (for instance, Guercif basin) have been excluded from the assessment of Moroccan territory because of their remoteness from CO2 sources that would make economically unavailable their use as potential storage sites.

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4. Costs of storage and ranking qualification of sites

4.1. Costs of storage

One of the key issues in every work regarding storage of carbon dioxide and its potential application in the region of study, is the cost of the process of exploration, implementation and operation of the storage sites. COMET has tried to establish the main costs that have to be evaluated in the West Mediterranean region. Obviously, these costs have a strong variation depending on the type of storage (saline aquifers, hydrocarbon fields), location (onshore, offshore), surface of the potential storage formation or the previous existence of wells or facilities. It is not the objective of this paper to get into details about the numbers used in each potential sink and the sensitivity of costs to these factors but it can be said that the range of costs is between 15 to 400 €/ton of CO_2 injected, although average values are circa 40 €/ton.

As every economic analysis of an industrial operation, COMET estimation of costs includes Investments needed, Capital costs and Operational costs, including monitoring and verification. The development cost (previous exploration and implementation of facilities) has been considered an investment, which strongly depends on the volume of the potential storage complex and its injectivity. In order to take in account these factors when studying final costs that will have a very strong influence in network modelling, COMET has developed a simple tool to calculate the most adequate number of wells for the operation of the field, taking in account engineering parameters such as depth, permeability, radius of influence of wells, interaction between wells, maximum increases of pressure or CO_2 density in storage conditions.

4.2. Ranking qualification of sites

Although storage structures can be just defined through their location, geometry and capacity, there are many other factors that will have an influence in the behaviour of the storage, such as injectivity, salinity, sealing rocks, etc. Many of these factors are studied within COMET and their values are included in generated databases. One of the goals of COMET is to use all available geological parameters in order to obtain a qualitative qualification of the storage sites (8). This qualification will be useful for network modellers who will use it as a tool to decide where most effective solutions can be found for linking CO_2 sources and sinks. it is not necessary to establish a very detailed qualification of sites, and it seems reasonable to define certain ranges of quality in order to distinguish those sites that present a better geological setting, in a way that models are not only based on economic issues.

Seven evaluation criteria were defined. These criteria take into account all relevant parameters and different aspects of site selection defined in the Site Selection Criteria report:
- **Storage formation quality.** In this criterion we take into account the adequacy of the storage formation to the injection. Therefore, when giving a range of quality for this formation, porosity, permeability, injectivity and net to gross relation must be the key parameters.
- **Sealing formation quality.** In this case, the evaluation will evaluate thickness, lithology and homogeneity of the sealing formation. This criterion is mostly based in the expertise of partners.
- **Capacity of storage.** Total CO_2 available to be stored at the selected site is a key factor. It has been considered that storage sites with bigger capacity may be used by different operators for a longer period of time, while some other smaller sites might be more difficult to use because of high investment costs and brief durability. Therefore, high quality values are given to sites with more than 50 Mt capacity, medium quality is assigned to those between 5 and 50 Mt and low quality to those under 5 Mt.
- **Hosting structure properties.** This value will take in account if the structure is open or closed, if it is fractured, complex, connected to large aquifers… Simple settings with high values of storage efficiency will be better qualified than those with very complex and fractured systems.
- **Other natural resources potentially affected by CO_2 storage.** Every country does have some peculiarities and priorities related to the use of its natural resources. In the specific case of the three participant countries, fresh water resources will always be prioritized over geological storages. Other conflicts might be related to hydrocarbons in some areas, essentially with deposits that might be used for strategic natural gas storage. The lowest chance of conflict the higher the value for this criterion.
- **Environmental and social issues in the area.** Sites might be too close to populated communities or environmental protected areas. In some cases, even the exploration of sites can be heavily hampered because of this issue. Therefore, the quality of the site will also depend on its capability to be operated without social conflict.
- **Quality of the exploration information.** Extended territories of the three participant countries are not explored or geological exploration has been very low. Deep saline aquifers have never been objective of boreholes or geophysical campaigns. Therefore, it is necessary to make a difference in the evaluation of

sites where data is more or less precise and others were key parameters can only be approximated by rules of thumb.

As all these parameters do not have the same relevance, different influence factors were assigned to each parameter in order to weight them towards the final decision. As a result of the evaluation of each parameter, a table calculates an average value. If the final value is between 2.5 and 3 the site will be considered "High quality". If it is between 2 and 2.5 it will be "medium quality" and under 2 it will be "low quality". Figure 8 presents an example of evaluation of the Dogger limestone in the Essaouira Basin .

	Storage formation quality	Sealing formation quality	Capacity of storage	Structure	Affected resources	Environment	Quality of the information	Total
Quality value	1	2	3	3	3	3	3	
Weight	0,25	0,15	0,2	0,1	0,1	0,1	0,1	
Value	0,25	0,3	0,6	0,3	0,3	0,3	0,3	2,35
Storage qualification	High quality							

Fig.8. Example of weighted qualification of the Dogger limestone aquifer in the Essaouira basin

A complete set of the qualification of sites is presented in the public report "Ranking qualification of storage sites". Ranking is not a final result of the evaluation work but a tool to assess modellers in the treatment of sinks.

5. Conclusions

- After COMET, there is a first detailed analysis of the storage capacity of the West Mediterranean region, including onshore and offshore territories and a potential cooperation in transboundary locations. This analysis has used all publicly available information in the three participant countries and only the use of information that remains confidential or the acquisition of new subsurface information could lead to new evaluations of storage sites.
- Storage capacity in the West Mediterranean region is large enough to uphold a great amount of the CO_2 that needs to be prevented from being released to the atmosphere in the next decades. If that potential ends up becoming a reality depends on the investments and the funding schemes needed for further exploration and characterization of storage complexes.
- Costs of storage in the West Mediterranean region are close to those reported in other areas of Europe or the United States. (9) COMET is the first detailed analysis in these costs and their potential sensitivity in the participant countries, although a further study of uncertainties is needed to obtain relevant conclusions.

- Some of the parameters that have been identified and quantified in the databases could not be obtained from direct measures. For example, permeabilities were usually obtained from groundwater studies at shallower depths than those needed for carbon dioxide geological storage. Frequently, geometrical description is based on poor seismic sections obtained several decades ago.
- Management of data from the oil industry is usually not easy, because of confidentiality issues. In any case, hydrocarbon fields could be a great opportunity for storage in the pioneer projects and confidentiality issues would not be a barrier if the industry is involved in these projects. In the participant countries, this is very common offshore while onshore most of the subsurface information is already public.

Acknowledgements

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