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METSTOR: a GIS to look for potential CO_2 storage zones in France

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Abstract

The METSTOR project offers a methodology to look for potentially interesting CO_2 storage areas in France at the initial stage, before the “site selection” step. Our tool, embodied in a Geographic Information System, is based on an interactive map of CO_2 storage capacities. Other relevant information layers are included. The geographic layers are complemented with a series of online technical notices. It seems to be the first open online GIS that offers policy makers, businesses and the public at large an integrated access to that necessary information. Our prototype, limited mainly to the Paris Basin, is released online at www.metstor.fr.

Keywords: CO_2 storage; Carbone capture and storage; Methodology; France; Site selection; Geographic Information System; Storage capacities; Aquifers; Coal deposits; Depleted fields; Risk assessment

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1. Introduction

1.1. Project background

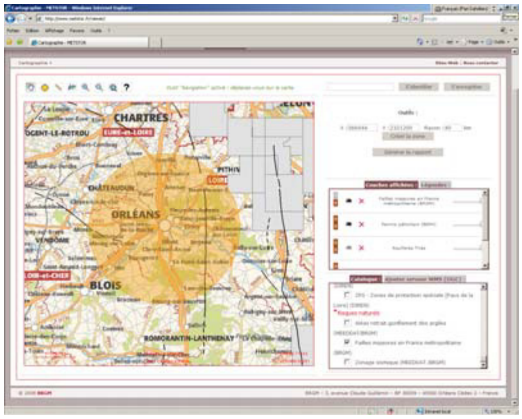
The METSTOR project was implemented by the BRGM, IFP, INERIS, Gaz de France, Géostock, Cired, University of Pau and IPGP under the auspices of the Ademe in the 2006–2008 period, to design a decision-making tool for initial selection of sites for geological storage of carbon dioxide (CO_2). Once successfully completed the project will provide information to industrial concerns interested in reducing their greenhouse gas (GHG) emissions and also inform the general public about the potential of techniques for capture and geological storage of CO_2.

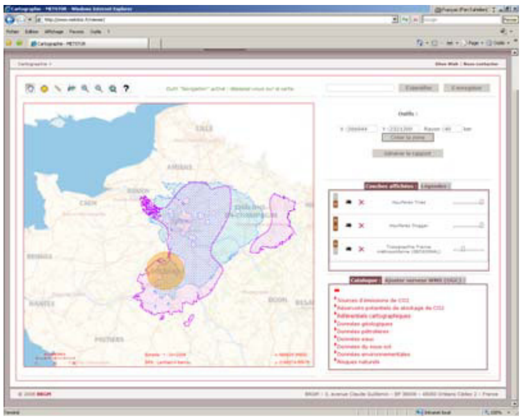
A website (www.metstor.fr) has been created to support this aim, providing clear, simple and accurate information on the various themes surrounding capture and geological storage of CO_2. This is supported by an interactive mapping engine that allows users to appropriate a methodology via a tool for assessment of geological storage capacities in a given area.

The global approach underlying the project led to a search for exhaustiveness in the results delivered to users: information is given on potential storage formations (aquifers, hydrocarbon deposits, coal beds, basic and ultrabasic rocks); on risks (seismic risk, environmental vulnerability, abandoned shafts, etc.); and on associated socio-economic issues (land use, nature reserves, etc.).

However, as for any project, the aim of METSTOR is not to deliver a merely publishable outcome but, via the creation of a demonstrator model, to evaluate the concept and identify and remove any possible obstacles so as to, ultimately, deliver a fully finished product able to give sufficiently accurate information for the complete mapping of storage capacities throughout metropolitan France.

1.2. System use scenarios





Take an industrial plant in the city of Orléans (100 km South of Paris, France) that is emitting CO_2. The management wishes to assess the feasibility of geological storage in the environs.

The mapper will show two potential CO_2 storage reservoirs; there are two possible geological formations: the Dogger (in blue) and Trias (mauve) aquifers in the Paris region. The orange circle traced out by the user (with a radius that must be between 20 and 100 km) underpins the estimations.

The report includes:

— cartographic information describing the study area;

— sources of CO_2 emissions greater than 100 kt/yr, with as many as 15 parameters per source;

—geological storage capacities: effective capacities of the Dogger and Trias aquifers, effective capacities of the hydrocarbon reservoirs and theoretical capacities of the coal deposits;

— additional useful information: existing wells, faults, oil extraction areas, protected areas, etc.;

In that example, an effective capacity of $\simeq$2 Gt can be deduced within the 40 km radius considered, entirely in the aquifers.

The GIS can also show additional information such as major faults (black lines) and oil extraction areas (grey areas).

1.3. GIS and technological projects affecting the environment

Communication instruments on CO_2 capture and storage often address the issue from a marketing point of view, i.e. with the intention of augmenting acceptability which is viewed as malleable and exploitable. The underlying assumption is that, since engineers are able to control all of the risks, effective communication is all that is necessary. Our approach is different, recognising that full and free access to information is now mandatory.

There is widespread agreement that one of the main factors influencing risk perception is the use of forms of planning that, as a necessity, include consultation ahead of the actual spatial planning phase and which do not therefore simply decide, announce and (possibly) gain acceptance in public opinion. In the public mind, citizens are able only to make judgements about the decision-making process, as they are not specialists in risk assessment. If the way in which policy is made is accepted and shared, then the technology will eventually become firmly rooted.

The Aarhus Convention, in force for some years now, makes provision of access to information and the possibility of public participation in environmental matters mandatory. An essential point is that participation is to take place when options and solutions are still open and the public can exert an effective influence, that is to say upstream of projects: a project proposed for discussion must be genuinely reversible and public participation must allow the choice between several possibilities as well as discussion of the very advisability of a project.

The public must, within reasonable timeframes, be provided with knowledge of the different procedural stages and must have access to all relevant information needed to understand the implications of decisions ‘freely and as soon as it becomes available’. In this regard, European Directive 2003/4/EC, which enacts the Convention, stipulates that all local authorities must provide all environmental information they possess to anyone requesting it (without the need for any proof of identity nor justification for the request).

METSTOR meets these requirements fully. It is a complement to modern consultation instruments that express technological development projects in terms of public policy rather than in terms of technical aspects that can be resolved via concepts such as energy, efficiency or probability.

The METSTOR GIS can be used by all of the stakeholders concerned by storage of CO_2 to give substance to discussions that go beyond the simple NIMBY effect to become mechanisms and channels for expression of different forms of support or opposition, usually conditional. The interlinkages and implications that arise from a geological CO_2 storage project include: reformulation of the relationship between environmental and economic or industrial issues, regional planning, land use, etc.

METSTOR does not therefore contain acceptability maps. Local acceptability of industrial projects is generally conditional (i.e. subject to different expectations) and usually varies between different social sub-groups. Its determinants include both historical trajectories and human factors (confidence, competence and perceived fairness, etc.). There is, therefore, no sensible ex ante reason for presenting a map of a variable such as potential acceptability of CO_2 storage. The available international literature does not include geographical factors in explaining opinions about the technology, as confirmed by analysis of the data obtained from a survey of the French population as part of the METSTOR project. The idea of an acceptability map makes sense not as the product of a GIS inter-relating statistical, technical and administrative factors, but as a product of public policy.

For similar reasons, an approach based on optimisation is not justifiable for METSTOR. In a multi-stakeholder, multi-criteria decision-making context where uncertainty is high the idea of an ‘a priori best site’ is groundless. Site selection is seen more as the result of a process of participation than as an optimisable technological variable. The maps METSTOR provides can merely support co-construction of local development projects.

2. Capacity calculation methods

2.1. Definitions of capacity from the Carbon Sequestration Leadership Forum

In practice, the capacity of a reservoir for geological storage of CO_2 is difficult to evaluate, but different levels of approximation have, nonetheless, been established. These values depend on numerous physical, geological and even economic parameters that are themselves often difficult to evaluate.

To prevail itself of a globally recognised standard, the METSTOR project relies on the considerations and approaches defined by the group of international experts of the Carbon Sequestration Leadership Forum (CSLF).

The CSLF distinguishes four steeps of storage capacities analysis in increasing order of evaluation accuracy:

— Capacities referred to as ‘theoretical’ which comprise the entire porous volume accessible to CO_2, fluid on gas saturation and maximum adsorption available in coal.

— ‘Effective’ or ‘realistic' capacities, supposing realistic reservoir behaviour: these capacities therefore include technical characteristics such as water saturation, fracturing of rock, heterogeneities, etc. They vary widely as new data and new knowledge are acquired.

— ‘Practical’ capacities integrate the socio-economic and regulatory constraints on storage. They may therefore evolve rapidly with technology, policies or economic conditions. Practical storage capacity corresponds to the ‘reserves’ of the energy and mining industries.

— ‘Matched’ capacities, which are those resulting from actual geological storage projects, when all parameters have been taken into account.

In METSTOR, the definitions used are those of theoretical and effective capacities. At present it is not possible to refine (practical) capacity calculations for an entire basin.

2.2. Effective capacities of hydrocarbon deposits

The partners in the METSTOR project have used operational data to calculate effective geological storage capacities of CO_2 for the Dogger and Trias oil fields in the Paris basin. The CO_2 storage capacity was evaluated assuming a two step process: an enhaced oil recovery phase followed by a storage phase (no production) when EOR was assumed to be uneconomical as too much CO_2 recycling was needed. Given that some of these data are not publicly available we have had to mask the calculation values as well as, for example, the exact extent of the fields.

2.3. Effective aquifer reservoir capacities

Deep saline aquifers at depths beyond 800 m are good candidates for geological storage of CO_2. These are porous and permeable geological formations at great depth that contain hypersaline water. Impermeable layers (clay, marns and salt) cap and underlie these deep aquifers forming a sealing barrier.

The METSTOR project investigated the geological CO_2 storage capacities of the deep saline aquifers in the Paris basin. Two target reservoirs, Dogger and Trias, were examined. Their wide geographical extent at depths of between 800 and 1000 m, their position immediately below points of CO_2 emissions and the existence of impermeable overburden layers guaranteeing sequestration made them places of choice for future injection and storage facilities.

The formulae recommended by the CSLF served as the basis for assessment of capacities (theoretical and effective). Irreducible water saturation was considered as constant for each aquifer: 20 per cent for Dogger and 30 per cent for Trias. Porosity was defined in accordance with schematic maps. Porosity varies within the Dogger aquifer through values of 0, 3, 6 and 12 per cent; 6, 7, 12 and 18 per cent in the Trias.

Effective capacity is deduced from the theoretical capacity by applying a capacity coefficient C_C. To evaluate the capacity coefficient, an equivalent calculated from available data on the hydrocarbon deposits in the Paris basin was used. C_C is approximated from the average over the Paris basin oil fields of the ratio of the volume of oil produced to the porous volume. The calculations give a capacity coefficient of 2.2 per cent for Dogger, 3.7 per cent for Trias.

Finally, and allowing for some imprecision in the model, the effective geological storage capacities in the Paris basin are estimated at 13.6 Gt of CO_2 for Dogger and 15.5 Gt for Trias, in consideration of the approximations needed. These figures are to be compared with those given under the GESTCO programme which assessed the theoretical capacities of the Paris basin Dogger at 4.3 Gt and at 22 Gt for Trias. Although going from theoretical to effective capacities normally results in a reduction in the capacities as a result of the integration of more accurate data, it nonetheless appears that the restrictions applied under GESTCO were too severe for Dogger.

2.4. Theoretical capacities of coal beds

Over and above its characteristics as an energy source, coal forms a heterogeneous and microporous environment characterised by a very great specific surface, and therefore by a high theoretical potential for gas storage. Coal can store gases in several ways:

— Adsorption at the inner surface of coal: physical phenomenon involves *a priori* the greatest storage capacity;

— Adsorption in the coal's molecular structure;

— As free gas in the voids available in the coal and surrounding rock strata (porosity and fractures);

— In solution in the deposit water.

CO_2 is adsorbed by coal in preference to methane (CH_4). There is therefore a possibility, in some geological contexts, of recovering and using the methane, offering a possible economic advantage.

Calculation was proposed and performed in the METSTOR project for a site in the Gardanne coal basin (South of France). The chosen level of accuracy of capacity was the theoretical capacity: total saturation of coal in terms of both free gas in porosity and gas adsorption. A more accurate study of the capacity will have to incorporate well distribution, the pressure field, anisotropy, heterogeneity, permeability, etc. To evaluate the theoretical CO2 storage capacity, formula specified by the CSLF have been modified and completed.

The formula applies to conditions of storage of CO_2 in the gaseous state. The mineral fraction of the coal (ash) is considered to be inert to CO_2. The adsorption capacity is determined from Langmuir theory. The formula states that the quantity of gas adsorbed at increasing pressure P tends towards a finite limit corresponding to saturation at all of the adsorption sites at the inner surface of coal. In practice, adsorption capacities depend on several other factors such as: the intrinsic characteristics of the coal, temperature, humidity, ash content, gas composition, etc. Similarly, several configurations are possible, depending on whether the coal bed originally contains gas or not (most often CH_4 and/or CO_2), and whether or not this gas is recovered prior to storage (as it is the case for methane).

The first study made on the basis of 100 km^2 unexploited area of Gardanne coal deposit made it possible to estimate the theoretical capacity of CO_2 storage only in the coal seams at about 70 Mt, for the coal beds situated between 500 and 1500 m of depth only. In the next step, a more accurate study of the capacity will have to incorporate other complementary parameters as porosity of surrounding rock strata, coal and rock permeability, injection wells characteristics and distribution, the gas pressure field, anisotropy and heterogeneity of coal deposit characteristics, etc.

Prior to CO2 storage, in-situ experimental studies should be carried out in the studied coal deposit, in order to determine the characteristics of the main seams and rock strata, and to estimate the storage capacity in the light of the various parameters and configurations presented above.

2.5. Basic and ultrabasic formations

Basic and ultrabasic rock formations—such as basalts, peridotites or serpentinites (hydrated periodotites)—are to be included in the formations usually considered as potential reservoirs for geological storage of CO_2. These formations are very common throughout the world, and some of them are close to sources of CO_2 emissions. The principal form of storage in these rocks is mineral sequestration (precipitation of carbonate or mineral carbonation), which has the advantage of high security over considerable periods.

Carbonation is obtained by weathering of rocks through the simple mineral reaction represented below:

$M SiO_3 + CO_2 \rightleftharpoons MCO_3 + SiO_2$, where M is the divalent cation.

The total area of continental France's territory covered by basic and ultrabasic formations is estimated to be 11.7 per cent of the country, the most widespread outcropping volcanic terrain being found in the Massif Central. The northern tip of Corsica also comprises basic and ultrabasic areas favourable for CO_2 storage.

In overseas territories, Nouvelle Calédonie has wide expanses of ultrabasic rocks (peridotites, serpentinites, etc.) covering around one-third of the emerged territory, the Grand Massif du Sud being one of the world's largest ultrabasic massifs. Moreover, intensive mineral exploration in these massifs has resulted in waste piles of these ultrabasic rocks that can be used for ex situ CO_2 carbonation. And lastly, Réunion Island, consisting entirely of basaltic rocks, could provide large *in situ* storage capacities. A lack of petro-physical or geophysical data on these formations makes estimation of the actual CO_2 storage capacities difficult at present.

3. Other factors mapped

The GIS allows the storage capacities to be viewed against numerous other relevant factors for initial site selection. To ensure this, simple access to a number of general references is provided via:

- Land use, Corine Land Cover 2000 (IFEN); *http://www.ifen.fr/bases-de-donnees/occupation-du-sol.html*
- Topography of metropolitan France (GEOSIGNAL base); *http://www.geosignal.fr/*
- Water courses (SANDRE basis); *http://sandre.eaufrance.fr/*
- Geological map of France (BRGM); *http://infoterre.brgm.fr/*
- Subsurface database (BRGM's BSS base). *http://infoterre.brgm.fr/*

The system allows users to superimpose their own layers hosted on a WMS (OGC) server. It also takes specific account of three additional factors. First, CO_2 sources in France have been mapped. Second, certain vulnerability factors can be represented: in particular, population density, protected areas, and a vulnerability index for the different environments. Third, maps of risk factors and recommendations for preliminary risk analysis are included.

3.1. Mapping of CO_2 sources in France

METSTOR GIS provides access to a localised inventory of the principal sources of CO_2 emissions in France. This geography of France's CO_2 emissions primarily covers units emitting at least 1 Mt of CO_2 per year. It is neither an official nor an exhaustive record. The database constructed gives the geographical position of the emitter, the type of target industry, the volume of CO_2 emitted annually and, in so far as possible, the composition of the gas emitted and its pressure. These data are obtained from three public databases: iREP, EPER−EU and GESTCO.

iREP: Le Registre français des Émissions Polluantes (French polluting emission register) (*http://www.pollutionsindustrielles.ecologie.gouv.fr/IREP*), into which operators' annual declarations are fed, meets the requirements of European Directive 96/61/EC on integrated pollution prevention and control (the 'IPPC' Directive). It is managed by the Pollution and Risk Prevention Department of the Ministry for Ecology and Sustainable Development, supported by the International Office for Water. The facilities covered are environmentally 'classified' facilities subject to a requirement for prefectoral authorisation, and more particularly those covered by the IPPC Directive. The register covers 100 pollutants with respect to water, 50 with respect to air and 400 categories of hazardous waste.

The European Pollutant Emission Register (EPER−EU) (*http://eper.eea.europa.eu/*) is the first pan-European register of industrial emissions to the atmosphere and to water. It was created by a Commission Decision of 17 July 2000. Under the EPER decision, Member States must produce a report every three years on emissions from industrial facilities into the atmosphere and into water (9 200 facilities in 2001, 12 000 in 2004). The reports cover 50 pollutants and, in practice, 90 per cent of emissions from the listed facilities are covered. In 2007, the EPER was replaced by the European Pollutant Release and Transfer Register (E−PRTR), which contains information related to: pollutants, activities and emissions to the air or to water (either direct or via the sewerage system).

GESTCO is an FP 5 project intended to assess the potential and technical-economic feasibility of sequestration of CO2 in deep aquifers, depleted oil and gas fields or deep coal seams. In this context, BRGM has made an inventory of the major industrial sources of CO_2 emissions in France, compiled from different data sources: the Centre Interprofessionnel Technique d'Études sur la Pollution Atmosphérique (CITEPA − inter-professional centre for technical study of atmospheric pollution), the Ministry for Industry and a Europe-wide inventory made by the Dutch company ECOFYS. CITEPA and ECOFYS have made an estimate of CO_2 emissions per facility via annual production weighted by an emission factor per type of production and annual duration of activity of the facilities.

3.2. Mapping of vulnerability factors

There are three aspects to vulnerability to risks arising from geological CO_2 storage: material, environmental and human. The common denominator allowing representation is the density of the targets.

METSTOR GIS provides a view of population density as recorded in 1999 by the INSEE (France's national statistics office), which appears as the initial vulnerability factor. Below, by way of example, are the recommendations of a panel of citizens, interviewed in 2008 (EPE survey), on living in a CO_2 storage zone. Panel members declared that they were willing to live in a CO_2 storage zone but nevertheless stressed the following conditions to reassure the population:

1. Information and awareness raising for the population as to the advantages of CO_2 storage (even though support of the population is not necessarily required).
2. Consultative approach via local commissions involving the population, public interest inquiries by appointed investigating inquirers.
3. Networking of cities concerned by CO_2 storage, with a view to sharing experiences with other cities.
4. Training for the population on management of health risks.
5. Close monitoring of the CO_2 storage site: installation of sensors, etc.
6. Population evacuation plan in case of problem, even minor.

7. The panel, nonetheless, recommended choosing places with low population density.

In a more refined study, other factors of human vulnerability will have to be considered. The locations and capacities of buildings in which members of the public congregate, such as schools or retirement homes, as well as communications infrastructure are generally considered in industrial risk studies.

For environmental vulnerability, METSTOR GIS shows two types of information: protected areas and a summary vulnerability index based on land use. The network of protected areas in France involves a variety of tools and instruments each with its own aims, constraints and (more of less constraining) management modes:

• Regional natural parks and agro-environmental measures come under a contractual local approach to protection and management. Development of economic activities is not generally excluded from these areas, with local stakeholders taking a stance that attempts to reconcile development and conservation.

• National parks and nature reserves come under a regulatory protective approach. These areas aim for long-term protection of heritage. The approach is closer to exclusion of human activities than to development.

• The Natura 2000 network is made up of special protection areas (SPA) under the ‘Birds’ directive and special conservation areas (SCA) under the ‘Habitats’ directive. These instruments provide protection at the European level; management is contractual and voluntary. Projects likely to significantly affect natural habitats and species on a Natura 2000 site must be subject to impact assessment. Public authorities may intervene to regulate access to certain areas or the practice of certain activities, especially industrial, in cases of overriding public interest, including economic interest.

The summary vulnerability index is based on land use. The geographical data employed use the European reference in the area of biophysical land use, the CORINE Land Cover (CLC) database, created in 2000, maintained and distributed by the Institut Français de l'Environnement (IFEN − French institute for environment).

The formula for calculating the index is adapted from the method developed by J. Tixier as part of the ARAMIS project. For each element of a 500 m square grid the sum is calculated of the areas of each of the four main categories of land cover listed in Table 1, weighted by relative vulnerabilities. Weightings are extracted from the ARAMIS expert survey of relative vulnerability of different environments, assuming a risk from CO_2 relating only to its toxicity and liquid pollution.

Table 1: environmental vulnerability indices per land use category (Source: ARAMIS expert survey)

Land cover (1st level CLC category)	Weighting
Agricultural areas	0.242
Forests and semi-natural areas	0.136
Protected wilderness	0.255
Wetlands and water bodies	0.367

The material vulnerability factors are the other economic activities that may be impacted by CO_2 storage. Some *Seveso* facilities may also impose constraints that need to be considered. The prevention policy for major industrial accidents in France sets high standards in controlling risk at source, response planning, control of urbanisation around risk sites, and provision of information to populations. Even if CO_2 storage is expected to have its own regulatory framework, these standards provide a reference for the levels of expectation of local communities.

3.3. Help sheets for initial risk analysis

METSTOR contributes to initial risk analysis in two ways. First, the system allows mapping of certain natural risk factors and then, going further, proposes a set of method sheets. Displayable risk factors relate to:

• Swelling and shrinkage of clays (MEEDDAT/BRGM) (*http://www.argiles.fr/*)

• Major faults in metropolitan France (BRGM)(*http://www.planseisme.fr/*)

• Seismic zoning (MEEDDAT /BRGM) (*http://www.sisfrance.net/*)

• Existing wells in Dogger and Trias (BRGM) (*http://www.infoterre.brgm.fr/*)

Each geological storage project is unique and it is up to the decision-maker to conduct a risk assessment suited to the context for all of the activities relating to implementation of storage within the framework of a global risk control approach. Implementation involves activities in both stationary facilities and transport. For each storage process associated with a manufacturing or stock management process, it will allow identification of a risk criterion representative of each underground storage process that will influence the decision-maker's choice.

The links in the CO_2 transport and storage chain within the scope of the METSTOR project are as follows:

• terrestrial pipelines from capture to underground storage without recompression or pressure reduction stations;

• stationary pressure regulation facilities (relief valve or recompression pump) upstream of wellhead;

• surface and underground injection facilities (wellhead, wells);

• CO_2 storage deep underground in geological formations: saline aquifers, exhausted oil and gas fields, unexploited coal beds and basic rocks.

Feedback on accidents involving CO_2 indicate two major types of accident that can be caused by the gas:

• First, leaks that have had toxic effects for humans, mainly releases in confined spaces.

• Second, explosions or gas emissions from vessels containing CO_2 in either gaseous or pressurised liquid forms. In the first instance, these are classic bursting of storage vessels. In the second, the term 'BLEVE' applies.

Leaks may occur in transport or at well injection facilities as a result of equipment failures or inflicted damage or destruction. Bursting of transport pipes with ensuing leaks cannot be excluded.

Moreover, even if one of the main criteria for choice of potential storage sites is low permeability of the overburden layers, some migration of the gas towards the surface cannot be excluded.

Where geological storage of CO_2 is concerned, it is therefore important to identify and assess the risks and to then select from amongst them the most important for the physical and human environment of the storage facility, so as to map them.

Risk is defined as a combination of the hazardous phenomenon probability (or frequency) of occurrence of a hazardous phenomenon, its intensity and the vulnerability of the area exposed to it. Estimating probability involves identifying initiating events, the causes of hazardous phenomena, and of estimating their frequency. It also involves identification and qualification of safety barriers which counter the progress of an accident scenario from the initiating event through to the hazardous phenomenon.

A methodology for risk analysis suited to the context of the METSTOR project has been developed. The main stages relate to identification of:

• technological risks of terrestrial pipeline transport and injection of CO_2 (short-term risk);

• risks related to gas leakage from the storage formation to shallower aquifers and/or to the ground surface through the following pathways: top seal (caprock), wellbore and (re)activated faults.

Risk assessment is the stage beyond risk analysis. It consists in deciding whether the risks identified are acceptable or are adequately controlled. This stage is not carried out formally in the METSTOR project, work being limited to an initial risk analysis provided to users in the form of information sheets.

4. Conclusion

The procedures developed in METSTOR, mainly in the Paris basin, prefigure a national map of estimated capacities for geological storage of CO_2. New data should become available from research in progress in the south-east of the basin. Interest could then switch to the Aquitaine basin and the Lorraine coal basin, to the basic and ultrabasic rocks of New Caledonia and to other aquifers in the Paris basin.

The procedures for assessment of storage capacities can be refined technically. A better definition of the geological parameters—e.g. density of super-critical CO_2 (depending on temperature and pressure)—or more precise capacity coefficients per aquifer (C_c) will make capacity estimates more accurate.

The improvement process introduced to meet users' expectations and needs includes several actions. Content of texts used must be updated to keep pace with developments in national, European and international practice, and a regular current-information roundup should be organised. A moderated forum would allow users to put forward their points of view and address questions to experts. Analysis of connection statistics allows for monitoring of actual use: requests leading to the site, points of entry and visitors route around the site, pages viewed most frequently, geographical and institutional characteristics of visitor's IP address. An attempt will also be made to assess the impact of the tool on public debate, via a media scan and through direct dialogue with the stakeholders in an actual geological CO_2 storage project.

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