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Evaluation of the CO_2 leakage risk along the abandoned wells in the French context

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Abstract

This paper presents a classification system, adapted from the Watson and Bachu (2007) one, to estimate the leakage risk along the abandoned wells in the French context. The selected criteria of this classification are the wellbore type (with/without casing that intercepts the aquifer where the storage will take place), the abandonment date (before/after 2000 which corresponds to a significant improvement in the French wellbore abandonment regulation), the top level of primary cementation, the deviation of the wellbore, and the drilling date (before/after 1980).

The input data necessary to establish the classification are mostly available. When a data is missing, we have considered either: 1) a most prejudicial option assuming that the maximum value is considered; 2) or less prejudicial option where the criterion does not affect the calculated risk category. The results show a great variability of the risk when one moves from the most prejudicial option to the less prejudicial one. This emphasizes the primary importance of the management of the lack of data in this kind of study. Thus, without any additional information, the evaluation of the CO_2 leakage risk along the abandoned wells should at least exhibit the two extreme values that respectively correspond to the less and the most prejudicial options.

Keywords: classification; leakage risk; wellbore integrity, CO_2 storage

1. Introduction

A preliminary step of any CO_2 storage project consists in selecting the most appropriate location to inject the CO_2. This step is fundamental as it will strongly influence the technical and economical evaluation of the project, and thus can affect its success.

As previously discussed by Grataloup [1], from the several targets that influence this selection, the safety of the storage is particularly important. Consequently, for this last point, the scanning of the abandoned wellbore distribution that can be affected by the potential storage is necessary. Indeed, the injected CO_2 could be in contact with abandoned wellbores penetrating the aquifers, and depending on the

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quality of the cementing job, or on the type of abandonment procedure or on the external solicitation that have stressed the well, they can either be considered as a sustainable barrier to CO_2 leakage or as a preferential leakage pathway to upper fresh water aquifers or to the atmosphere (e.g. Wertz et al. [2], Nordbotten et al. [3]).

However, in these preliminary studies, it should not be economically feasible to quantify precisely (with geophysical tools for example) the leakage potential of each wellbore near each scanned storage location. Actually, in order to select the optimal storage location, it should be sufficient to have an estimation of the leakage potential through a classification based on data that can be easily found in official reports.

To do so, we relied on the classification of Watson et al. [4] on the risk of CO_2 leakage (shallow leakage criteria) in the Alberta sedimentary basin. Then we have applied this classification to the French data base "deep wells" of Vernoux et al. [5], which collects information from drilling and abandonment reports of 3482 wells within the Seine-Normandie basin.

This audit showed that the criteria are available in this data base with the exception of two criteria that are not available for all wells. To calculate the risk of CO_2 leakage from each well, numerical values reflecting the influence on the potential of wellbore to leak, are assigned to each criterion, and where a data is missing in the data base, two options are considered. In the first option, the maximum values are assigned to criteria, whereas in the second one minimum values are allocated to them. So the leakage risk, which is regarded as the product of risk criteria, is calculated for each well, and four risk levels are defined. A geographic information system (GIS) is then used to visualize the wells and their corresponding risk level.

2. Identification of the risk criteria

In order to build the classification, the first step is to identify the criteria that drive the risk of leakage. According to the studies from Khodadadi [6] and Wojtanowics et al. [7], the operator, the well location, the material used (casing/cement type, etc.), the well geometry, etc. seem to be the key items. However, the main problem is the quantification of the impact of these criteria on the risk of leakage. On that point, an important work was made by Watson et al. [4; 8], where the impact of these criteria is evaluated form the analysis of the leakage occurrence from Gas Migration and Surface Casing Vent Flow Measurements on more than 500 wells in the Alberta sedimentary basin (Canada). In the following, this classification system is adapted to the French context. The Dogger formation is considered as the target reservoir and the following criteria are taken into account:

- Well type (cased well or not): We consider that a well is cased if it has a cased interval which intercepts the reservoir (Dogger). Indeed, the casing intercepting the reservoir is interpreted by Watson et al. [4] as additional CO_2 leakage sources (through the interfaces), increasing occurrences of SCVF (Surface Casing Vent Flow) and GM (Gas Migration)
- Abandonment date: before/after 2000, which corresponds to a significant improvement in the French wellbore abandonment regulation
- Cement to surface: this criterion is assigned to a well if it has at least one cemented interval that reaches the surface (z = 0)
- Well deviation: A well is deviated if its total vertical depth (TVD) is less than its total depth (TD)
- Spud date: this criterion that permits to take into account the age of the well, is compared to 1980 corresponding to the inflexion point of the distribution curve of the total number of wells between 1954 and 2003 [5]

To test the applicability of this classification, the database developed by Vernoux et al. [5] under an agreement between BRGM and the French Water agency is used. This database is composed of 2590 oil wells, 119 geothermal wells, 435 natural gas wells and 338 water wells. The main table of this data base gathers the main characteristics of wells, namely, their identification number, type, cementing, casing, and plugging characteristics, their Lambert coordinates, depth, and dates (end of drilling, and abandonment). It is also related to other tables that complement the description of wells. Additional information about the fluids within the wells, the cement types, geological levels crossed by wells, cementing and casing descriptions, may be found in these secondary tables of this data base.

Within these wells, we need to select the abandoned wells "likely" to intercept a CO_2 storage site. In this study, we considered the aquifer of the Dogger (Jurassic), which is one of the two deep aquifers traditionally regarded as a target for CO_2 storage in the Paris Basin.

All wells reaching at least the Middle Jurassic are supposed to reach or impact the Dogger aquifer. However, only areas where the top of the Middle Jurassic is deeper than 800m have been considered. The limit of 800 m corresponds to the depth at which the temperature and pressure conditions keep the CO_2 in a supercritical state, guaranteeing the injectivity and storage capacity.

There are 216 wells in the data base that reach the Middle Jurassic and therefore expected to intercept the Dogger aquifer, which represents about 7% of the total number of deep wells. Table 1 summarizes the availability of information within the database to estimate if a risk criterion is reached or not.

Table 1. Availability of data in the 216 abandoned wells likely to intercept the Dogger aquifer

Criteria	Well type	Abandonment date	Cement to surface	Well deviation	Spud date
Availability	85.6%	57.87%	100%	100%	100%

3. Calculation of the risk of CO_2 shallow leakage

The calculation of the risk of surface leakage associated with each well supposed to intercept the Dogger aquifer is made by assigning a weighting coefficient to each criterion. The overall risk is obtained by multiplying them. There is no universal rule to estimate these values, but they are classically estimated through experience feedback. Without any further information, the values determined by [8] and reported in Table 2 are used in the present study. The maximum value of the overall risk that may be associated to a well is 900, while the minimum value is 1. The mean overall risk through the 216 wells, taking into account the lack of information, is equal to 133.6, while the standard deviation is 60.

Table 2. Weights assigned to criteria for the calculation of CO_2 surface leakage risk, taking into account the lack of information. According to Watson and Bachu [8]

Criterion	Value
Cased well	8
Uncased well	1
Lack of information	8 or 1
Abandoned before 2000	5
Abandoned after 2000	1
Lack of information	5 or 1
No cement to surface	5
Cementing intervals unknown	4
Other cases	1
Deviated well	1.5
Non deviated well	1
Spud date before 1980	3
Spud date after 1980	1

Moreover we have seen that wellbore reports and database cannot always give us all the information we need to evaluate the value of all criteria. Then, when information is missing, we have decided to consider the two following extreme cases:

- The MIN case: Whatever the criterion, we assign the minimum value (1) in the case of a lack of information. This is the case considered by [8]
- or the MAX case : Whatever the criterion, we assign the maximum value associated to the criterion in the case of a lack of information

4. Risk levels

Using the values of table 2, a risk tree of 32 branches has been determined (five criteria, two possibilities for each criterion and therefore $2^5 = 32$ branches, cf. Figure 1). Some branches are overlapped. The risk tree shows four risk levels:

- **Elevated risk**: the CO_2 surface leakage risk of the well is greater than or equal to 200 and less than or equal to 900. In the risk tree, the wells being at this risk level are those with casing, abandoned before 2000 and without cementing to surface
- **Mean risk**: the CO_2 surface leakage risk of the well is greater than or equal to 40 and less than or equal to 180. In the risk tree, the wells being at this risk level are those with casing, abandoned before 2000 and with cementing to surface, those with casing, abandoned after 2000 and without cementing to surface, and those without casing, with spud date before 1980, abandoned before 2000 and without cementing to surface
- **Low risk**: the CO_2 surface leakage risk of the well is greater than or equal to 24 and less than or equal to 37.5. In the risk tree, the wells being at this risk level are those with casing, abandoned after 2000 and with cementing to surface, and those without casing, with spud date after 1980, abandoned before 2000 and without cementing to surface

- **Very low risk**: CO_2 surface leakage risk of the well must be greater than or equal to 1 and less than or equal to 22.5. In the risk tree, the wells being at this risk level are those without casing, abandoned before 2000 and with cementing to surface, and those without casing and abandoned after 2000

Considering the MIN and MAX cases, we obtain the distribution of risk levels shown in Table 3.

Table 3. Comparison of distributions obtained on the risk levels in the two approaches

	Elevated risk	Mean risk	Low risk	Very low risk
“MIN” case	26.39%	34.26%	10.65%	28.70%
“MAX” case	56.02%	25.46%	12.04%	6.48%

In the MAX case where the lack of information maximizes the risk, we note that 56.02% of wells have a high risk of CO_2 surface leakage. This distribution is explained by the fact that 122 of the 216 wells (56.5% of wells) have a casing that may intercept the Dogger reservoir, 84% of wells have cement to surface and 95% have been abandoned before 2000 (because of the manner we have taken into account the lack of information) and these three criteria are very disadvantageous for wells that verify them.

In the MIN case, the manner to take into account the lack of information leads to minimize the risk (value of lacked criterion is 1), we notice only 26.39% of wells with a high risk of CO_2 surface leakage, while the number of well with a low risk rises from 6.48% to 28.70% of total number of wells.

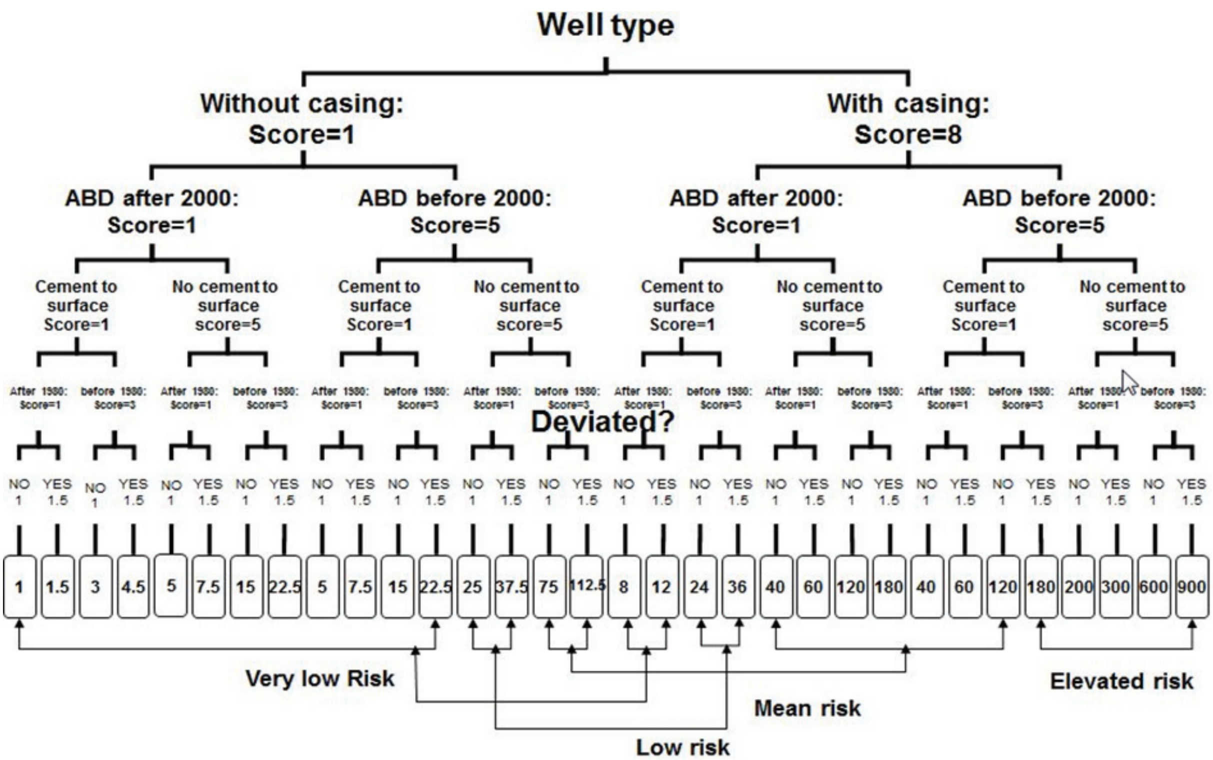

Fig. 1. The risk tree used to derive the risk levels

To have a spatial vision of the impact of lack of information, the results (MIN and MAX cases) are putted into a GIS. The resulting maps in Figure 2 emphasize that the classification is strongly influenced by the way that the lack of information is managed. Indeed, in the MIN cases, a CO_2 storage south-east of the Paris region appears to induce a risk of CO_2 leakage by wells from low to very low (only a few wells at high risk of CO_2 leakage should be taken into account), while in the MAX case, a medium to high risk would seem to prevail.

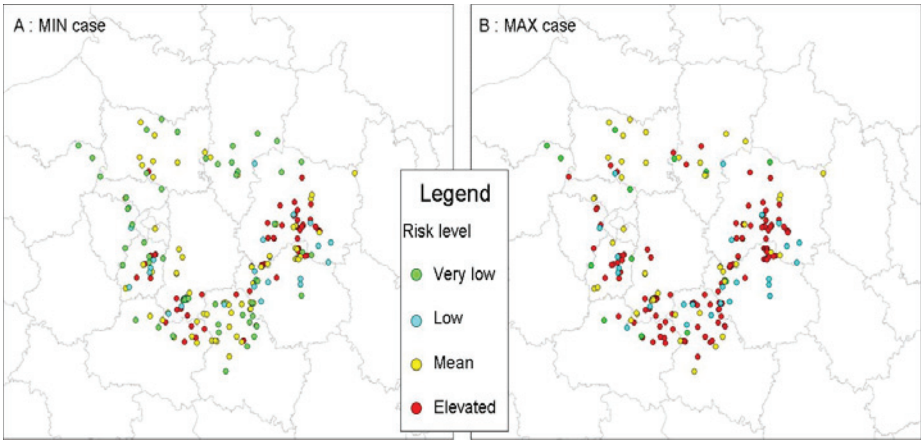

Fig. 2. Mapping of results of the analysis of the risk of leakage through abandoned wells in the Seine-Normandy basin

These results clearly show the dependence of the results on how the lack of information has been taken into account. Thus, one must be careful in using the results of such a classification, rather than entering each well in one risk level, we recommend to attribute to each well the two risk levels associated with the "MIN" and "MAX" cases. So two maps would be generated for each CO_2 storage site, and it would be left to the decision makers, according to their knowledge of the studied Basin, to choose the most appropriate map.

5. Conclusion

This paper shows the application of a wellbore classification system within the Paris Basin, France. The input data necessary to establish the classification are mostly available. When data is missing, we have considered either: 1) a most prejudicial option assuming that the value of the criterion linked to this data is maximum; 2) or less prejudicial option where the criterion is not taken into account in the computation of the risk category (i.e., considered value is equal to 1). For the most prejudicial case, the results show that 55% of the wellbores that reached the selected deep saline aquifer (i.e. the Calcareous Dogger of the Paris Basin), are in the worst risk category. This high risk level can be explained by the fact that 56.5% of the selected wellbore have a casing that intercepts the aquifer, 84% are not cemented to the ground level and 95% were abandoned before 2000. On the contrary, if we consider the less prejudicial case, only 25% of the studied wellbore are in the worst risk category. This emphasizes that the management of the lack of data is of primary importance in this kind of study. Thus, without any additional information, the evaluation of the CO_2 leakage risk along the abandoned wells should at least exhibit the two extreme values that respectively correspond to the less and the more prejudicial options.

Unlike the Alberta basin, there are very few records of gas leakage from abandoned wells in the Paris basin and in France in general, making it difficult to derive a classification of abandoned wells according to their potential to leak. This is why we believe that using the adapted classification of Watson et al. [4, 8] in the Paris Basin, might be very useful.

However the methodology used to classify the wells according to their risk level of leakage has its limitations since it does not take into account any changes in the integrity of the well in the long run. In future works, we therefore propose to investigate through numerical simulations the impact and thresholds of new criteria related to the environment around the well (chemical composition of fluid initially saturating the aquifer, the type of rocks intersected by the well, the in situ temperature and pressure, and stress regime).

Acknowledgements

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