Annals of
Reviews and Research

Review Article
Volume 7 Issue 5 - August 2022
DOI: 10.19080/ARR.2022.07.555722

Ann Rev Resear

The Design of an Integrated Informatics System for Digital Monitoring, Management and Information of Social Partners Regarding the Safety of CO_2 Storage

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Submission: August 08, 2022; **Published:** August 18, 2022

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Abstract

The two authors, together with an international team of researchers, are involved in a project, DigiMon "Digital monitoring of CO2 storage" which aims to create a configurable, hierarchical, distributed monitoring system for CO2 storage that will ensure safety in exploitation. The overall objective of the DigiMon project is to accelerate the development of an affordable, intelligent, flexible and society-integrated digital monitoring early warning system for monitoring CO2 geological storage reservoirs. The objectives are to develop and combine distributed fiber optic sensing technology, seismic point sensors and gravimetry with Ethernet-based digital communications and web-based intelligent real-time data processing software with social partner risk information potential in the area. Decision Support Systems (DSS) supports the choice of concept and solution, assisting the decision-maker in organizing information, modeling results and making decisions as an operator guide. The concept proposed by DSS aims, based on a system structure, to provide help in formulating alternatives, accessing data, developing models and interpreting their results. The social partners that must be informed are defined by the legislation of each country and have a role in monitoring environmental risk situations and crisis management.

This paper presents the system concept and the component blocks and their role.

Keywords: Carbon Capture System; CO2 gelogical storage; Digital Monitoring; SCADA system; Social partners

Abbreviations: DSS: Decision Support Systems; CCS: Carbon Capture and Storage; MMV: Measurement, monitoring, simulation and verification; TRL: Technological readiness levels; DAS: Distributed Acoustic Sensing; ANI: Ambient noise interferometry; SCADA: supervisory control and data acquisition

Introduction

The goal of the project is to develop and combine distributed fiber optic detection technology, seismic point sensors and gravimetry with Ethernet-based digital communications and web-based intelligent real-time data processing software. The system will be flexible and configurable in terms of the environment (offshore or onshore) correlated with the new components provided by the development of existing technology on the market. The key functions of any Carbon Capture and Storage (CCS) Monitoring System are measurement, monitoring, simulation and verification (MMV), as well as management of information that must demonstrate that projects are planned and executed in a socially and environmentally acceptable manner. A CCS system should be profitable in operation, ensuring the safety and security of people and data and will have a special focus on communication and dissemination of knowledge to decision-makers (internal and external to the exploitation) and the local public (from the impact area). The project involves the development and integration of system components, available at the highest technological readiness levels (TRL). Its objective is to develop the system components to a uniformly high TRL, prior to the integration of the components into the early warning system. One of the most critical R&D challenges central to the project is the integration of a wide range of technologies for MMV at CO_2 storage sites (i.e. distributed fiber optic sensing (DxS) technology, seismic point sensors, seafloor pressure and gravimetry).

Combined with Internet and Ethernet-based digital communication and web-based real-time intelligent data processing software, the project presents a novel, cost-effective early warning solution for monitoring CO_2 geological storage reservoirs and underground CO_2 barrier systems (caprock). In addition, it takes into account, in a unique and integrated way, the need to monitor technologies for CCS from the point of view of society's acceptance, up to the limit of the impact zone, of maintaining safety and trust and of the benefit in operation. Such a system is desired by the CCS industry and other industries that exploit underground or chemical resources. For this purpose, a strong, interdisciplinary international consortium was established with leading research institutions and industry representatives from Norway, the Netherlands, Germany, United Kingdom, the USA, Romania and Greece, supported by implementing partners, with expertise in the field.

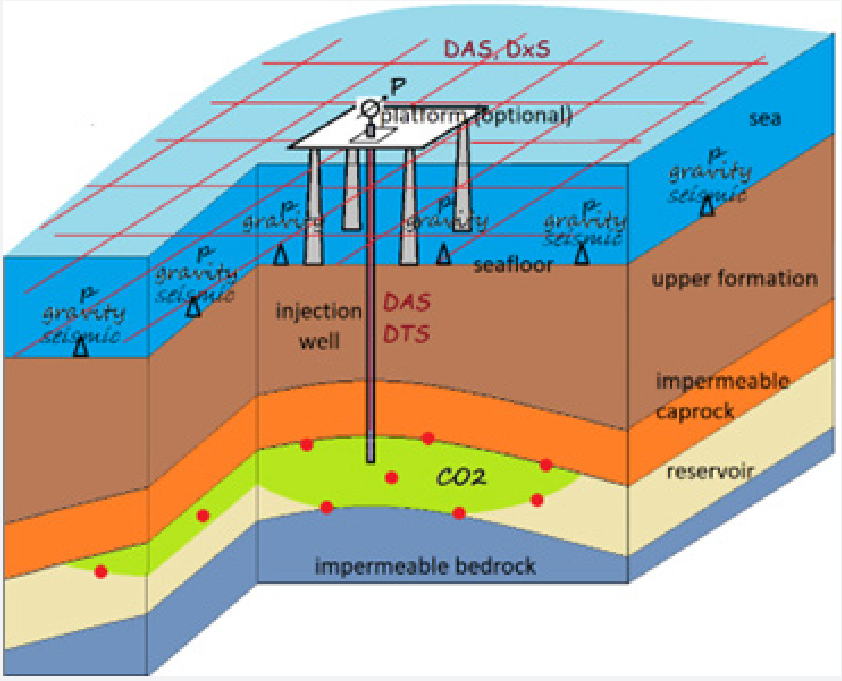

Figure 1: The DigiMon Digital Monitoring Sensors at a CO2 geological storage site

This paper will explore the system concept and the block components of the system that will assure the necessary functions. From a technological point of view, the CCS chain consists of three parts: capture of carbon dioxide, transport of carbon dioxide and safe storage of carbon dioxide emissions, underground, in depleted oil and gas fields or in deep salt formations. First, capture technologies allow the separation of carbon dioxide from gases produced in electricity generation and industrial processes through one of three methods: pre-combustion capture, post-combustion capture and oxygen with fuel combustion. The carbon dioxide is then transported by pipeline or by ship for safe storage. Millions of tons of carbon dioxide are already transported annually for commercial purposes, by tanks, ships and pipelines. The United States has several decades of experience in transporting carbon dioxide through pipelines for oil recovery and other projects.

Carbon dioxide is then stored in storage spaces, made up of carefully selected geological rocks, which are usually located a few kilometers below the earth's surface. At every point in the CCS chain, from production to storage, the industry has a number of process technologies that are well monitored, managed and known and have excellent records of population health and safety. The commercial development of CCS involves the widespread adoption of these CCS methodologies and techniques, combined with robust monitoring techniques and government regulations. CCS is a technology for combating climate change in a controllable way, delivering economic growth and regional prosperity. The industry already has the skills and experience and has the solutions and technologies to provide CCS safely. CCS is one of a number of technologies needed to combat climate change, including renewable energy, nuclear energy and energy efficiency.

Technical and scientific description

CO2 storage in geological reservoirs is a key component of most strategies to reduce greenhouse gases in the atmosphere. CO_2 is captured at emitters, such as power plants, and is injected through deep drilling holes in subsurface storage reservoirs (carbon capture and storage - CCS). A number of measurements, monitoring and verification (MMV) strategies can be used to ensure that CO_2 remains in place. As a regulatory requirement, MMV plans must demonstrate Compliance (that models are aligned with monitoring data), verify Content (be able to ensure that there are no leaks), and provide Contingency plans (taking corrective action in in case of a leak) for CO_2 storage projects. A number of demonstration and commercial CO_2 storage projects have shown that CCS is technically feasible. However, this operation needs to be implemented at 1,000 sites if it is to be an effective tool for reducing CO_2 emissions.

The overall goal is to demonstrate the commercial availability of a digital monitoring system that is suitable for cost-effective and socially accepted CO_2 storage MMV.

The system will focus on:

i. Monitoring the movement of CO_2 plume within the reservoir using mainly remote passive geophysical measurements and modeling saturation and pressure changes (compliance monitoring).

ii. Monitoring the integrity of the well, mainly by detecting downward pressure, temperature and rock tension (monitoring of retention and contingency).

iii. Overload (caprock) monitoring, including monitoring of CO_2 migration from the upper area and early detection of anomalies (retention and emergency monitoring).

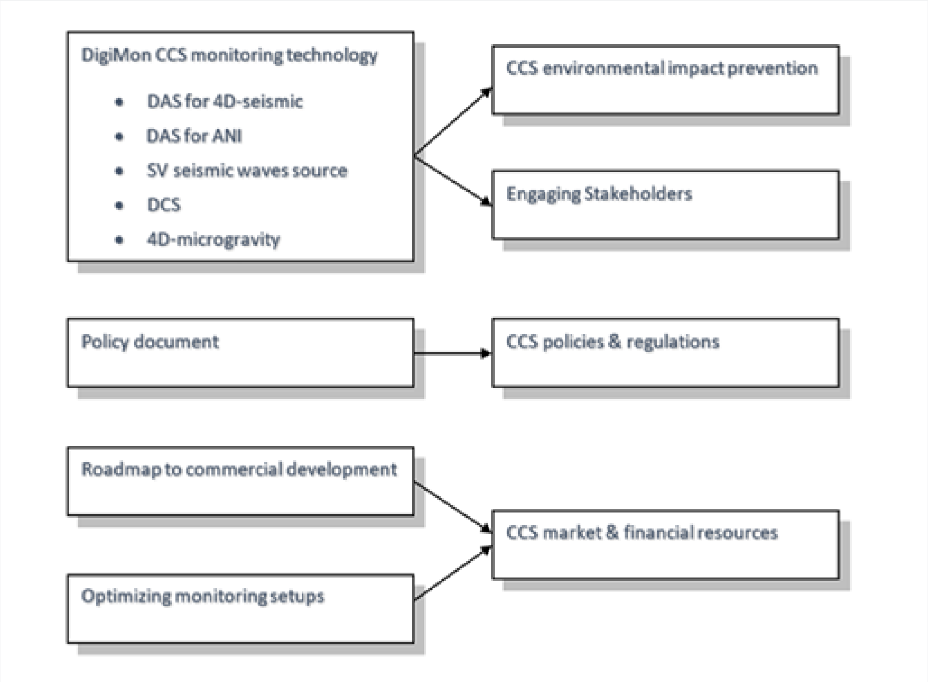

Figure 2: Relationship of technological developments (left) with requirements towards a societal embedded monitoring system (right).

Designing a monitoring system focused on human safety

Public support is vital for the development of CO_2 storage projects. Lack of public support weakens political support, reduces deployment and accessibility, and may require alternative technological configurations and risk management practices Watson, Kern, & Markusson, 2014. The lack of political support has already hindered the deployment of CCS in some countries Raven, Kern, Verhees and Smith, 2016. Specific projects have also been cancelled due to local public opposition, for example in Barendrecht, the Netherlands Cuppen, Brunsting, Pesch and Feenstra, 2015 and Beeskow in Germany Dütschke, 2011. Public opposition is sometimes explained as a lack of knowledge or misunderstanding about the planned CO2 storage projects Susskind, 2011. Local communities may also resist a project because of the direct visual, environmental and socio-economic impact Petrova, 2016 or because the project does not match the culture of the local place Devine-Wright & Batel, 2017. However, in many cases, it is not a lack of knowledge, but a lack of trust in systemic issues, so stakeholders simply do not believe what they are told. One of DigiMon's goals is to find out if and how these CCS monitoring systems can help alleviate local communities' concerns about any impact. However, the support of these communities for the project is based primarily on the equitable distribution of costs and benefits, the correct decision-making process and the building of trust in developers and governing authorities Van Engelenburg & Puts, 2015 and also to clarify what are the possible benefits for the community [1-6].

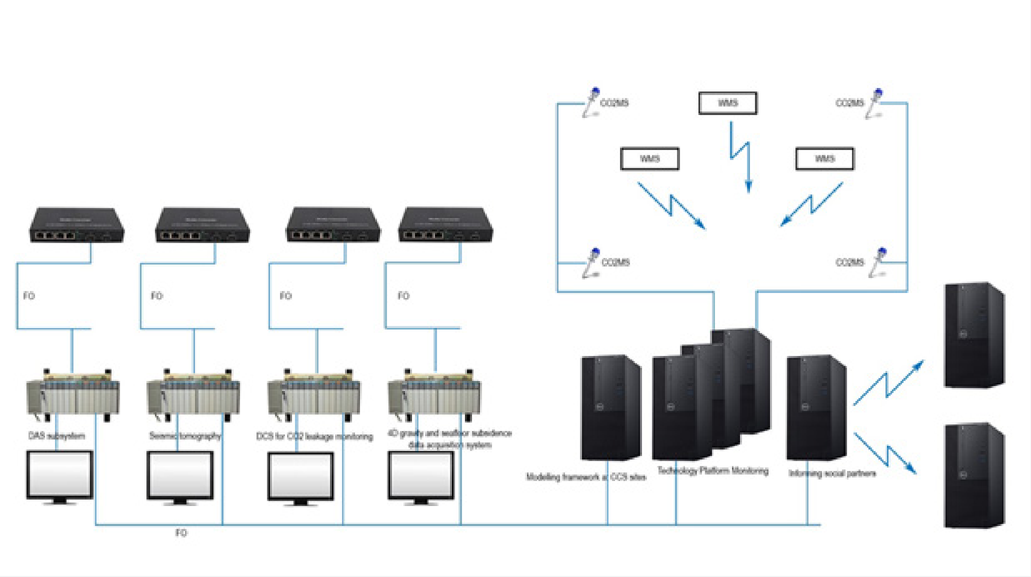

Figure 3: Block diagram of the informatics system.

Previous infrastructure and energy projects show that not only the involvement of all relevant stakeholders in the decision-making process is crucial, but also how different perspectives, conflicting interests and concerns are considered in the design of the project in time Duijn, Puts & Boxem, 2013. Moreover, research in the sociology of ignorance has shown that clear communication of uncertainties and knowledge gaps and even insignificant results can increase trust in an organization and technology, as long as the arguments brought to the public are perceived to be honest and congruent with deduced motives of the organization or scientists involved cf. Maxim and Mansier 2014. Despite all these perspectives on the social factors influencing the success of the development and implementation of CO_2 storage projects, research has also shown that in the transition to low-carbon energy systems, technological change, rather than social change, is a priority constantly in debates. The political attraction of CCS as an important approach to climate change mitigation shows the trend towards technological optimism and how the promises of technological corrections have dominated the political discourse around climate mitigation. This is also linked to the fact that, in public discourse, the real impact of a possible leakage of CO_2 from a geological storage reservoir is often perceived uniformly as a high-risk impact. However, the impact of different leak scenarios and the real danger to health and the environment is highly variable. Breaking high-pressure pipelines can lead to fatal explosions or clouds of suffocating gas, while an underground release of CO_2 can lead to the release of less CO_2 at slow speeds into the atmosphere, but with little or no human impact [7-14].

Today's public perception suggests all the above cases as detrimental to the operator's reputation. An approach focused only on communicating the benefits of monitoring to the public is unlikely to encourage project support even Orange Seigo, Wallquist, Dohle, & Siegrist, 2011. Previous research programs on mining have found that the participation of all relevant stakeholders and the consideration of their perceptions, interests, questions and concerns about a project or technology are key factors for the integration of new energy technologies in society and promote procedural justice, trust and confidence, in project developers and government authorities and public support for the project Duijn & Puts, 2013

). Societal embeddedness of a CCS monitoring system is characterized by 4 dimensions, which are the impact on environment, stakeholder involvement, policies and regulations, and market and financial resources. In terms of monitoring aspects, they are translated as follows:

a) Towards reducing or preventing CCS environmental impact

b) Towards engaging organizations or individuals involved or affected by CCS

c) Towards developing and complying with CCS policies and regulations

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d) Towards mobilizing market and financial resources for CCS projects

The challenge is to create an informatics SCADA system that integrates all the facilities.

Assessments for CCS performed during the DigiMon project, show that monitoring currently is a regulatory requirement as part of permitting procedures, which may alleviate community concerns on safety. In order to effectively contribute to trust-building among stakeholders, a CCS monitoring system should be low cost, efficient and easy to maintain over a long time, measure and predict leakages and plume movement, transparent, allowing real-time access to monitoring data, provide continuously reliable access to experts for questions on the data, externally supervised by unbiased institutions and connected to a safety concept that states what happens when the data divert from normality. Insights from the local assessments indicate that monitoring is perceived as useful towards ensuring site safety, protecting groundwater resources, safeguarding the environment, minimizing the possibility of induced seismicity, identifying possible leakage, and providing information on CO_2 emissions reductions.

Relevance with technology developed during the project

The relevance of developed CCS monitoring technology components to societal aspects are graphically summarized in next Figure below.

Contribution towards reducing/preventing environmental impact of CCS

Technological developments are all directly related to the environmental dimension of the societal embeddedness, by providing cost efficient methods to monitor and reduce the impact to the environment of CO_2 geological storage. The instrument response and site response determination, as well as the development of processing techniques for micro seismic data of a Distributed Acoustic Sensing (DAS) system allows recordings to be converted to velocity in a similar way to the conventional methods used for geophones. This permits a DAS fibre-optic system to map the subsurface seismic velocity field in a geological storage site. The evolution of seismic velocity field over time can provide an image of CO_2 plume location and expansion, as well as an early warning of potential CO_2 migration in the water table or potential leakages at the sea floor or ground surface. 4D seismic can provide qualitative information on the outline of the CO_2 plume. DAS advantage is their low cost, the ability to cover a wide area with continuous measurement sampling (e.g. every meter) and time lapse (4-D) recordings, while the corresponding equipment (fiber and electronics) can be installed on permanent basis within wells, sea-floor or at surface.

The application of DAS fibre-optic in ambient noise interferometry (ANI) surveys further expands available options in this aspect. For the purposes of monitoring CO_2 storage sites using DAS, ambient noise interferometry (ANI) has the potential to provide cost-effective, repeatable measurements for early warning of leakage. Potentially fiber-optics combined with ANI could offer wireline operation free, permanent CO_2 storage monitoring capability.

The development of instrumentation, data processing, modelling and visualization tools of the novel SV seismic waves generating source, allows the use of DAS fiber-optics for cross well seismic velocity tomography. Cross well seismic velocity tomography in essence provides direct calibration to depth of seismic surveys, making possible CO_2 plume mapping and its evolution at depths greater than 400 m, where seismic velocity calculations accuracy from surface recordings alone drops below the level required to identify velocity changes related to CO_2 movement. Cross-well seismic experiments could be enhanced or made more cost effective by a distributed acoustic sensing (DAS) fiber. The development of a new fiber for CO_2 detection and testing it via laboratory and field experiments coupled to modelling CO_2 diffusion in fiber, allow direct detection of CO_2 leakages in the environment. This is particularly important for monitoring well integrity, which can provide early warning for an incoming well failure and potential CO_2 leaking through it. The development of data acquisition techniques and processing software for a time lapse microgravity survey provide another accurate and cost-efficient method for subsurface CO_2 plume mapping and evolution, by defining the subsurface density distribution. Coupling with a distributed strain sensing (DSS) fiber-optic system will provide a cost-efficient mapping of seafloor or ground surface deformation and the necessary calibration to the density data. 4D gravity is valuable to quantify the mass changes within the reservoir, the density of the CO_2 plume and thereby the fraction of dissolved CO_2 in the reservoir brine.

System structure presentation

The objectives are:

i. Integration of the constituent subsystems of the DigiMon system in a coherent and unitary informatics system aiming to ensure the functions proposed by the project

ii. Elaboration of the structure of an IT system for increasing the safety in operation in units subject to technological risk

iii. To define a communication system between the sensors / equipment's situated in the technological field and the control room

iv. To set the sub-systems and the functions they assure

v. Elaboration of the structure for IT system to communicate with social partners

vi. Homogenization of information between the social partners interested in the system

A standard system and variants (minimum and maximum) with the possibility of integration in stages will be designed. We proposed a modular, configurable, distributed and open system for monitoring and control of the technological process, monitor-

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ing the utilities and informing the decision and information factors (inside and outside the technological unit), in a format specific to the attributions and the workplace. The monitoring system can be adapted and extended in successive stages and interfaced with applications so as to cover the requirements of a security and emergency response system, operating in conditions of technological risk. In order to control the technological process, the industrial management, in safe conditions in operation on the Technological Platform, it is necessary to interconnect the SCADA type subsystems in a unique system of acquisition, processing, monitoring and data transmissions to form the basis for the Intranet of the Technological Platform. Through this approach, the unitary vision of the concepts of technological risk, industrial safety, accident prevention through real-time monitoring of the technological process is realized.

The subsystems we want to integrate in the unitary, coherent SCADA system are:

a) DAS subsystem

b) Seismic tomography

c) DCS for CO_2 leakage monitoring

d) 4D gravity and seafloor subsidence data acquisition system

e) Seafloor pressure sensing or DSS for seafloor deformation monioring

f) Modelling framework at CCS sites

g) Technology Platform Monitoring

h) Risk analysis, simulation and management

i) Informing social partners

The structure of the functional blocks of the informatics system is shown in the figure below.

Subsystem informing social partners

We connect the technological challenges with the social factors that determine to which extent CO_2 storage projects will fit into their societal environment. The DigiMon project therefore researched how monitoring can be used as a risk management instrument. A key question is whether the monitoring system developed during this project can be a tool for improving the implementation of CCS projects. The research also included what conditions for monitoring are included in current regulatory frameworks, what type of monitoring approaches can be used to best communicate possible risks to different stakeholder groups (including a concerned public), and how does an all-in-one system as developed in DigiMon influence public understanding, acceptance, and trust. The social partners who need to be informed are defined by the legislation of each country and have a role in monitoring environmental risk situations and management in crisis situations. The social partners could include the pertinent Inspectorate responsible for Civil Protection and the pertinent Inspectorate responsible for Environmental Protection. Data obtained by acquisition and processing, from transducers and sensors as well as data characterizing the evolution of the subsurface CO_2 plume, or the potential evolution of the gas cloud in case of leakage, are transmitted specifically to the social decision makers. In case of accident, these data are presented on the map of the region highlighting: the place of the accident, estimating the amount of gas escaped, weather parameters in the immediate vicinity of the outbreak, estimating the shape of the cloud and its speed, highlighting possible scenarios and intervention measures.

The necessary information, which is transmitted, is:

i. The quantity of gases emitted into the atmosphere

ii. Framing between technological limits of operation

iii. Wind direction and intensity

iv. The evolution of the gas cloud superimposed on the map of the region

The system allows the detection and modelling of accidental gas discharges that may occur in the vicinity of technological installations, as follows:

a) Detection and surveillance of gas discharges in the vicinity of technological installations

b) Monitoring of METEO parameters in the meteorologically significant neighborhood

c) Gas cloud modelling based on both real-time data taken from subsystems and performance algorithms for modelling and estimating cloud evolution.

d) Remote reporting of information to decision-makers inside and outside the unit (informing the social partners) in order to make optimal decisions.

Reliable measurement and prediction of subsurface CO_2 plume movement are very important features of the CO_2 storage management system. They can be achieved by developing a continually updated reservoir model, which will also allow early warning of possible undesired incidents. Combining different monitoring methods, data and models will further improve monitoring and early warning reliability. Continuous monitoring can be achieved with the aid of a software monitoring program. A near real-time monitoring and alarm system is necessary accompanied by weighting awakening, alarm and risk levels. Autonomous operation would lead to cost reduction, but it should be under human supervision, onsite or remote.

Passive monitoring methods provide an environmentally friendly low-cost alternative to active monitoring methods. Identified trade-offs are:

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I. Between environmental impact and costs, where caution is required to avoid activation of local community, and

II. Between environmental impact and precision measurements, where priority should be given to the latter.

Conclusions

The international project DigiMon aims to create a monitoring configurable informatics system for CO_2 geological storage sites, which can accelerate the implementation of Carbon Capture and Sequestration projects and to demonstrate the commercial availability of a digital monitoring system that is suitable for cost-effective and socially accepted CO_2 storage MMV. One of DigiMon's goals is to find out if and how these CCS monitoring systems can help alleviate local communities' concerns about any impact through informing social partners. The other goal is to mitigate the risk by keeping the installations within technological limits, and to provide information to decision makers for optimal decision making. The security of legacy supervisory control and data acquisition (SCADA) systems has come under intense scrutiny as a result of homeland security initiatives being put in place to protect the nation's critical infrastructure. Data obtained by acquisition and processing, from transducers and sensors as well as data characterizing the evolution of the subsurface CO_2 plume, or the potential evolution of the gas cloud in case of leakage, are transmitted specifically to social decision makers. In case of accident, these data are presented on the map of the region highlighting: the place of the accident, estimating the amount of gas escaped, weather parameters in the immediate vicinity of the outbreak, estimating the shape of the cloud and its speed, highlighting possible scenarios and intervention measures. The system developed within the Digi Mon project is open and hierarchical, flexible and configurable and meets all technological, management and social requirements.

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