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RECOMMENDATIONS ON THE STEPS TO ESTABLISH A R&I  
ACTIVITY 4 EUROPEAN STORAGE ATLAS

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<https://www.ccus-setplan.eu/>

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# RECOMMENDATIONS ON THE STEPS TO ESTABLISH A R&I ACTIVITY 4 EUROPEAN STORAGE ATLAS

## Summary

The CCU and CCS Implementation Plan of the Implementation Working Group 9 (IWG9) has prioritised the establishment of a European CO<sub>2</sub> Storage Atlas as a flagship activity that will:

*"assist project developers and relevant permitting authorities to prioritise the most prospective areas for both onshore and offshore CO<sub>2</sub> storage, and will enable the design and development of transport infrastructure to be optimised."*

This report describes the benefits, objectives and potential functionality of a European CO<sub>2</sub> Storage Atlas. It provides a basis and high-level principles for the development of a European CO<sub>2</sub> Storage Atlas (hereafter referred to as the 'Atlas'). This report is based on a report produced by members of the IWG9 Storage Group and members of the European Energy Research Alliance's Joint Programme on CCS.

The initiative to develop the Atlas will require coordinated effort from a number of stakeholders and will require some new funding to support this effort. A proposed timeline and high-level budget for the development and subsequent maintenance and update of the Atlas is proposed.

Open access to information on the locations of potential CO<sub>2</sub> storage sites, and the related storage capacities, is necessary to increase the rate and geographical spread of CO<sub>2</sub> transport and storage infrastructure in Europe. Practical solutions for unlocking confidential information on potential storage sites should be found so that swift development of storage sites is enabled. A storage Atlas and related CCS database could fulfil this function.

An Atlas, together with its underlying database, has many benefits; it should, inter alia:

- Communicate the distribution of storage resources and the amount of existing knowledge about each storage site to decision makers;
- Enable easy access to common, publicly available data on storage sites to inform policy;
- Identify areas where exploration of storage potential is needed, as indicated by regional data;
- Inform strategic development of transnational transport and (interconnected) storage networks;
- Flag storage sites for private sector investment;
- Highlight oil and gas fields and saline aquifer structures prioritised for storage;
- Allow and encourage ranking of storage sites.

In order to maximise the benefits of both pre-commercial, and private sector appraisal, an Atlas can enable the prioritisation of future storage site development by country, region, size, suitability, unit cost, timing and location. This will enable Operators and Ministries to identify the high priority next candidates. This may be particularly important for depleted or end-of-life oil and gas fields and associated assets where consideration



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of change of use to CO<sub>2</sub> storage should be encouraged, including making available critical information, data and geological models that can support lower cost, higher quality and quicker assessments of CO<sub>2</sub> storage suitability.

The main objective of the Atlas should be to provide an overview of sites that are suitable or prospective for secure long-term storage of CO<sub>2</sub>. It will provide locations and characteristics, together with information on emitters and transport corridors, end of life estimates (where possible) for hydrocarbon fields and other geoenergy resources in order to demonstrate the European potential for CCS deployment and facilitate acceleration of development. This will provide stakeholders and decision makers with a robust Decision Support System (i.e. a tool to collate knowledge and analyse the storage potential in a user-defined area).

The main aims of the Atlas should be to:

1. Develop consistent and comparable estimates of storage capacity to enable site selection for further detailed appraisal and strategic planning of transport and storage infrastructure;
2. Provide an overview of CO<sub>2</sub> storage potential in various parts of Europe
3. Provide an open, up-to-date and easily updateable (in its online form) inventory of the most suitable and cost-effective geological storage capacity;
4. Create a portfolio of storage sites that would greatly assist project developers and relevant permitting authorities to prioritise prospective areas and identify early opportunities both onshore and offshore, integrating regional or national planning of storage transport development;
5. Play a major role in public communication and dissemination initiatives concerning CCS;
6. Provide data for policymakers and other users to enable techno-economic assessments of the feasibility of CO<sub>2</sub> storage;
7. Acquire geological data to obtain an estimate of reliable storage capacity for policymakers, by taking into account geological characteristics that might impact on capacity, containment and injectivity.

The Atlas should be a web portal with basic information for CO<sub>2</sub> Storage across Europe. The data sources for the Atlas will be based on the national data from each participating country and the (processed) data for the Atlas will be stored in a dedicated database and maintained by a dedicated data manager. It is expected that most countries will host and maintain their own national data and the Atlas should provide an overview of national datasets with links to direct access to existing national CO<sub>2</sub> storage atlases. It should be operated by a European organisation, such as EuroGeoSurveys (EGS), which has close links with its national counterparts to acquire input from the national data for maintenance and possible future updates. In some countries, other organisations, rather than the national geological survey, are responsible for development of national datasets and in those cases they will be considered as direct contributors to the Atlas compilation. Not being a member of EGS will in no way be a barrier to contribution in the development of the Storage Atlas.



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Presentation of the new Atlas in form of a publication, both online and report, will support the awareness of CO<sub>2</sub> storage potential availability in Europe and the visibility of the CCS technology as a whole.

Previous EU Framework Programme projects (such as the Joule II (1993-1995); GESTCO (2000-2003); CASTOR (2004-2008) and EU GeoCapacity projects (2006–2008)) have provided a foundation for the Atlas. However, most of these projects utilised confidential data, which has not been possible to publish in the public domain. Although the subsequent CO<sub>2</sub>StoP project is considered an important move towards a database with a consistent methodology, the low budget available prevented most countries from gathering new data, providing a complete inventory of potential storage sites and including larger data updates. Therefore the resultant database is incomplete and partly obsolete, and the understanding of the sites is of low maturity. The European Commission Directorate General for Energy (Directorate General for Energy, DG ENER) has published the CO<sub>2</sub>StoP database on the European Commission (Directorate General Joint Research Centre, DG JRC) website<sup>1</sup>; and thereafter allowed EGS to publish the GIS atlas via their European Geological Data Infrastructure (the “EDGI Platform<sup>2</sup>”). The updated CO<sub>2</sub>GeoNet State of Play on geological storage of CO<sub>2</sub> (CO<sub>2</sub>GeoNet, 2021) indicated that considerable work on identifying storage potential and collating data has been undertaken since CO<sub>2</sub>STOP and therefore there are new data which are now readily available for addition to a new consolidated European storage Atlas.

We recommend that the EDGI platform is also the most appropriate mechanism for publishing the new Atlas. We are concerned that providing two different data bases to decision makers will be confusing and the resulting differences in capacity figures will not foster stakeholders’ trust in geoscientific capacity assessments.

<sup>1</sup> [https://setis.ec.europa.eu/european-co2-storage-database\\_en](https://setis.ec.europa.eu/european-co2-storage-database_en)  
<sup>2</sup> <http://www.europe-geology.eu/map-viewer/>



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## Introduction

The CCU and CCS Implementation Plan of the Implementation Working Group 9, has prioritised the establishment of a European Storage Atlas as a flagship activity to “*assist project developers and relevant permitting authorities to prioritise the most prospective areas for both onshore and offshore CO<sub>2</sub> storage, and will enable the design and development of transport infrastructure to be optimised.*”<sup>3</sup>

Specifically “a European CO<sub>2</sub> Storage Atlas identifying and characterising all recognised prospective storage sites on a consistent basis is needed to facilitate site comparison, site ranking, and integrated regional or national planning of storage and transport development. The Atlas will greatly assist project developers and relevant permitting authorities to prospective areas and identify early opportunities for both onshore and offshore CO<sub>2</sub> storage, and will enable the design and development of transport infrastructure to be optimised” (R&I Activity 4).

*This report hopes to provide some principles by which R&I Activity 4: Establish a European Storage Atlas, will be achieved and summarises the potential objectives of the Atlas and proposes the uses and functionality that could be achieved. This report describes the governance and operating principles that might allow the Atlas to be implemented thus meeting Target 5 of the CCS and CCU Implementation Plan:*

*An up-to-date and detailed inventory of the most suitable and cost-effective geological storage capacity (based on agreed methodology), identified and accepted by various national authorities in Europe.*

This report is developed by members of the Storage Subgroup of the IWG9, supported by participants of the European Energy Research Alliance’s Joint Programme on CO<sub>2</sub> Capture and Storage (EERA CCS JP).

<sup>3</sup> [https://setis.ec.europa.eu/system/files/set\\_plan\\_ccus\\_implementation\\_plan.pdf](https://setis.ec.europa.eu/system/files/set_plan_ccus_implementation_plan.pdf)



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## Context and purpose for a European CO<sub>2</sub> storage atlas

The challenge of climate change demands reduction in global carbon dioxide (CO<sub>2</sub>) emissions. In order to fight global warming, many countries are looking at technological solutions to achieve these reductions. One of the most promising techniques is Carbon dioxide Capture and Storage (CCS) which has been shown to be one of the more mature of the proposed solutions. Geological storage of CO<sub>2</sub> is a key component of CCS. It has been estimated that the use of CCS can contribute up to 1191 Gt CO<sub>2</sub> total emission reductions to 2100, according to some scenarios to limit average global temperature rise to 1.5 C (IPCC, 2018). CCS usually involves a series of steps: (1) separation of the CO<sub>2</sub> from the flue gases produced by large power plants or other industrial point sources, (2) compression of the CO<sub>2</sub> for efficient transport and storage, (3) transportation to a storage location and (4) injecting it into deep underground geological formations.

The primary purpose of a publicly available CO<sub>2</sub> Storage Atlas is to provide an integrated database of CO<sub>2</sub> geological storage resources for Europe and tools to interrogate and visualize the data. The overall objective is to provide technical information to support development of strategies and policies for reduction of CO<sub>2</sub> emissions via CO<sub>2</sub> storage. The atlas is not an end in itself, it is a living publication intended to help accelerate development of CO<sub>2</sub> storage.

## A CO<sub>2</sub> storage atlas to inform development of European emissions reduction policy

The Atlas will inform policymaking and shall be available to various levels of society, *inter alia* public and politicians, industrial and business developers, researchers and students. This will enable effective communication within the whole CCS community. Additionally, it will enable planning and development of CO<sub>2</sub> transport infrastructure and for the development of geological storage resources for CO<sub>2</sub>.

Policymakers need reliable and robust data on storage areas and capacities, including information about inherent uncertainties, on which to assess the role that CCS can play in a portfolio of greenhouse gas mitigation options. We believe that policymakers will need to know:

1. The amount of geological CO<sub>2</sub> storage capacity available;
2. The level of confidence in the estimated storage capacity volume;
3. The geographical distribution of the storage resources;
4. When the estimated capacity will be available ;
5. The estimated rates of injection
6. The anticipated time for development of the storage reserve
7. The likely level of investment required to evaluate suitability of storage complexes and provide sufficient knowledge to be ready for injection.



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## Why is a European Storage Atlas needed?

Developing CO<sub>2</sub> storage is a time-consuming task with exploration, characterisation and development that may take 5 years or more. Open access to information on the locations of potential CO<sub>2</sub> storage sites and the related storage capacity is deemed necessary to swiftly initiate transport and storage infrastructure development in Europe, as has been noted by ZEP (2017). Practical solutions for unlocking confidential information on potential storage sites have to be found so that unnecessary delays in the development of storage sites are avoided. A storage atlas and related CCS database could fulfil this function, for example by providing generalised information.

A storage atlas will also help in meeting the legal requirement that potential users have transparent and non-discriminatory access to sites for the storage of produced and captured CO<sub>2</sub> (European Commission, 2009: Article 21).

In addition to national, regional and municipal authorities, the industry and power sectors will also need to build confidence in the viability of developing transport and storage networks in their regions of interest, as part of a strategy or plan for the deployment of CCS. One of the basic questions in developing CCS networks is where the potential storage sites are located with respect to the sources of captured emissions. A storage atlas will enable comparisons between sites to prioritise them in developing regional or national plans for transport and storage.

For the development of individual storage sites, the atlas will support “project developers and relevant permitting authorities to prioritise the most prospective areas for both onshore and offshore CO<sub>2</sub> storage, and will enable the design and development of transport infrastructure to be optimised” (cited from SET-Plan TWG9 CCS and CCU (2017)).

Establishing the European CCS Atlas will be an important step for wider and more rapid realisation of CCS in Europe to reduce CO<sub>2</sub> emissions and achieve reduction targets.



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## What are the benefits?

An Atlas and the underlying database offers many benefits, with the principle objective to promote and accelerate the development of CO<sub>2</sub> geological storage to reduce emissions in Europe. The benefits of such an atlas and database are multiple, it will:

- Illustrate the distribution of storage resources and knowledge;
- Enable easy access to common publicly available data on storage sites to inform policy;
- Identify areas where exploration of storage potential is needed;
- Inform strategic development of transnational networks;
- Promote collaboration to generate innovative transport & storage networks;
- Flag storage sites for private sector investment;
- Highlight those oil and gas fields prioritised for storage;
- Provide tools to assess and plan CO<sub>2</sub> capture, transport and storage;
- Communicate the existing level of understanding of prospective storage sites (for example by using Storage Readiness Levels<sup>4</sup>);
- Indicate the level of investigation/investment needed at sites for storage readiness;
- Apply a standardised calculation of storage capacity calculation and estimated injection rates to allow comparison of sites;
- Provide an online updatable tool;
- Promote CO<sub>2</sub> storage sites development.

## Communicate resources and knowledge to European decision makers

European decision makers will have a visual compendium of the potential sites, in each member country, to **communicate the distribution of European geological storage resources and the current level of knowledge**. The underlying data about the subsurface geological composition and properties of prospective storage sites, based on or derived from publicly available and confidential data, provides transparency on the source of accessible information which has a double benefit. Firstly, helping to show CCS as a feasible and achievable technology to counter climate change in Europe. Secondly, informing public awareness for deployment of CCS projects on a large scale throughout Europe.

<sup>4</sup> A framework developed in the ALIGN project to describe the level of understanding of individual sites or how 'ready' a site is for operational CO<sub>2</sub> storage. The SRL framework captures all the work that has gone into the assessment of a geological site for storage of CO<sub>2</sub> (Akhurst et al., 2021 <https://doi.org/10.1016/j.ijggc.2021.103402>).



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Importantly, the atlas will also illustrate and **identify areas with little or no knowledge of CO<sub>2</sub> storage information** where future exploration for storage potential should be undertaken, in particular near highly industrialized regions across Europe.

## Inform strategic transnational development

Visualisation of industrial CO<sub>2</sub> sources and natural geological storage sites will highlight the potential for European CCS project development capacity to inform, stimulate, and **promote collaboration amongst countries in developing innovative CCS projects**. The development of CCS networks would greatly benefit from a European atlas, as these networks will not be limited to national borders. International alliances may use the atlas to develop transboundary infrastructure, such as the Projects of Common Interest<sup>5</sup> being developed around the North Sea region. It is expected that CO<sub>2</sub> transport and storage will develop with a pan-European reach in order to enable delivery of a functioning network of commercial transport and storage services, as supported by the proposed amendment to the London Protocol to enable cross-boundary transport of CO<sub>2</sub> for storage in deep geological formations and as exemplified by the proposed Northern Lights transport and storage service.

Geospatial datasets displayed within the atlas will inform transnational strategy development for industrial-scale projects, connecting potential storage capacity to industrial sources in different territories. At the same time, a broad and reliable shared knowledge base of storage capacity could enhance the efficiency of collaboration between European public sector bodies, such as regional government ministries. Cross-sector sharing and access to atlas data, can reduce the cost of storage site assessment by avoiding duplication of effort and thus unnecessary expenditure.

The Atlas could make a significant contribution to national strategies to reduce greenhouse gas emissions and, at the same time, it is an opportunity for governments to support investments that return public benefit. Storage capacity identified by public sector-funded investigations can, in turn, **attract private sector investments in CCS**, as noted by UK industry use of the CO<sub>2</sub>Stored database<sup>6</sup>. In particular, an Atlas can **highlight oil and gas fields to be prioritised for storage** with known capacity, storage properties and timing of availability.

## Assess and plan CO<sub>2</sub> capture, transport and storage

The European Commission strongly supports the use of large databases as **tools for the development of common policy**. Databases can improve efficiency of public administrations, economic growth in the private sector and a wider social welfare. The CO<sub>2</sub> storage atlas, implemented by the collaboration of numerous public bodies, research institutions, universities and industries, will include tools to assess and plan transport and storage of captured CO<sub>2</sub>. The publicly available tools will help countries to reduce both costs and

<sup>5</sup> See <https://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest>

<sup>6</sup> <https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal>



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geological risks during the early stages of planning of CCS deployment by directing the characterisation effort towards the areas with highest potential for the necessary storage capacity. The Atlas will assist in decisions on whether CCS should be included in the portfolio of technologies that a country or region should employ to meet climate targets. Through a Geospatial Information System (GIS) connected to the information portal of the Atlas, information, knowledge, and common tools will be more effectively disseminated compared to current dissemination practice.

The suite of Atlas geospatial tools will include illustration of how ready a prospective site is for operational CO<sub>2</sub> storage. Application of CO<sub>2</sub> Storage Readiness Levels to sites within the storage atlas will **communicate the existing level of understanding of stores** to technical and non-technical decision makers. Storage Readiness Levels are a communication tool developed by European CO<sub>2</sub> storage researchers based on the planning and operation of CO<sub>2</sub> storage sites from first identification to site operation<sup>7</sup>. The levels indicate what is already known and what site assessment, permitting and planning is needed for a site to become operational. Application of the SRL framework allows comparison of sites, both within a national portfolio and more widely, when assessing potential for a transnational European transport and storage network. The levels also **indicate the investigations and investment needed to achieve an operational site** as they are benchmarked against the time taken and effort expended for planned and operational European sites. This provides a first-order estimate of effort needed.

## Standardise estimates of storage capacity

The Atlas will provide information from different European countries on the latest and best available estimates of potential CO<sub>2</sub> storage capacity that is essential to allow strategic planning of storage development. The Atlas will also provide an estimate of injection rates for each storage option, which is an essential property when selecting prospective storage sites to match expected CO<sub>2</sub> delivery rates. It will apply an internationally recognised **standardised methodology** across all of Europe, which is also used in Canada, USA and Australia. In this way, the Atlas will give added value to the heritage public databases in each of the participating European countries. The output will highlight each national potential CO<sub>2</sub> storage capacity. An easier access to information, data and knowledge about storage potential in each European country will contribute to the development of innovative services and inform new business models through the development of plans for storage deployment.

## Online updatable data

Provision and access of the Atlas using web technologies will ensure that storage potential data across Europe will always be available via an **online updatable tool**. The CO<sub>2</sub> Storage Atlas will incorporate the latest capacity appraisals and application of the database tools and establish links to those European countries with ongoing programmes that update their national CO<sub>2</sub> storage databases. An updateable format will

<sup>7</sup> <https://www.alignccus.eu/about-project/work-package-3-storage>



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accommodate and make available the latest information from CO<sub>2</sub> storage research results and industry CCS project plans and avoid misleading out-of-date information. It is envisaged that updates would be derived from national programmes, and implemented using dedicated resources for the Co2 Storage Atlas.

## Promote CO<sub>2</sub> storage sites development and cost reduction

Reduction of storage development costs by targeting site selection and appraisal promotes the development of a positive business case for deployment of CCS at industrial scale in a broader span of European countries than at present. Overall, the Atlas concept promotes collaboration, sharing of data and knowledge between current hydrocarbon field operators, regulators, future storage developers supporting strategic development of a number of operating CO<sub>2</sub> storage facilities. Projects that are ‘one of many’ will promote lower costs, reduce perceived technical and financial risks, avoid market failures and achieve economies of scale. Reaching significant levels of cost reductions in the longer-term requires immediate action today. The online publication of the Atlas should be one of these actions, as its detailed development and timely publication will support scale-up to realise economies of scale.



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## The objectives of the European Storage Atlas

According to the EU Energy Roadmap 2050 and recent communications on achieving Europe's commitments under the Paris Agreement, Europe needs to apply CO<sub>2</sub> geological storage from around 2030 in the power sector in order to attain emission-reduction targets (EC, 2018). The SET-Plan also asserts that "A European CO<sub>2</sub> Storage Atlas identifying and characterising all recognised prospective storage sites on a consistent basis is needed to facilitate site comparison, site ranking, and integrated regional or national planning of storage and transport development" (Set-Plan ACTION n.9-Implementation Plan, 2017).

The main objective of the Atlas is to provide an overview of prospective regions for further exploration and sites that are suitable for secure long-term storage of CO<sub>2</sub>. It will provide storage site locations and characteristics, together with available CO<sub>2</sub> capture and transport infrastructure, end of life estimates (where possible) for hydrocarbon fields and other resources (e.g. geothermal, water, gas storage including future hydrogen storage) in order to demonstrate the potentiality of Europe for a full and widespread adoption of CCS technology. This will provide stakeholders and decision makers with a robust Decision Support System required to implement CCS in their countries/regions. An Atlas is a priority for improving the cooperation and coordination of CO<sub>2</sub> geological storage experts from government agencies, as well as academia and industry.

The aims of a CO<sub>2</sub> storage Atlas are to:

1. Develop consistent and comparable estimates of European storage capacity (in terms of both total mass of CO<sub>2</sub> that can be stored and feasible rates of injection) to enable site selection for further detailed appraisal and strategic planning of transport and storage infrastructure;
2. Provide a pan-European overview of CO<sub>2</sub> storage potential
3. Provide an open, up-to-date and easily updateable (in its online form) inventory of the most suitable and cost-effective geological storage capacity (based on agreed methodology<sup>8</sup>) identified in each European country;
4. Create a portfolio of storage sites that would greatly assist project developers and relevant permitting authorities to prioritise the most prospective areas both onshore and offshore, integrating regional or national planning of storage transport development;
5. Serve public communication and dissemination initiatives concerning CCS;
6. Provide enough data to support policymakers in technoeconomic assessments of CO<sub>2</sub> storage.
7. Acquire geological risk data (i.e. geological characteristics that would require further assessment in order to demonstrate appropriate capacity, containment and injectivity) to obtain an estimate on amount of reliable storage capacity for policymakers.

The Atlas should be subject to the FAIR (Findable, Accessible, Interoperable and Reusable) data principles.

<sup>8</sup> Methodologies to consistently evaluate storage capacities will be defined, including risk and liability assessments and techno-economic assessments, in addition to geological assessments.



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# RECOMMENDATIONS ON THE STEPS TO ESTABLISH A R&I ACTIVITY 4 EUROPEAN STORAGE ATLAS

## Who needs the Atlas?

The atlas will be of use to a wide variety of stakeholders including governmental authorities, industry, non-government organisations and will be available to various levels of society, from public to local and national decision makers, investors, project developers, researchers and students. This will support effective communication to the whole CCS community and acceleration of technological development for CCS.

Policy makers can evaluate the potential for CO<sub>2</sub> storage and CCS in their region or look for strategic cooperation with other regions in towards emission reductions included in the Nationally Determined Contributions (NDCs). In meeting the goals in the NDCs, in particular when CCS is part of the mitigation portfolio, countries will have to develop living transport and storage plans or roadmaps supported by consistent policy messaging; including lists of high-ranking potential storage sites, based on high-level, standardised risk assessments. The Atlas will be an important basis for the impact assessment of CCS related policies. Regulators will be able to assess the potential for arising conflicts and synergies in existing regulations for, inter alia, mining, petroleum, safety, environment and spatial planning.

For industry consortia, it is crucial to understand the potential of CO<sub>2</sub> storage within reach of their industrial network or clusters to develop strategies and plans for deploying CCS. Open access to the information on storage potential will help developers of storage projects to quickly identify promising prospects.

The public atlas as an independent source of information can be informative for the public to judge if and where storage options in their region are located. Similarly, environmental NGOs can evaluate if there are environmental concerns near storage prospects, which would require particular attention.



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## Functionality of the Atlas

### Data sources

The Atlas should be a web portal with basic information for CO<sub>2</sub> Storage in Europe. The data sources will be based on the national data from each participating country and the data for the Atlas will be stored in a dedicated database and maintained by a dedicated data manager. In addition, the atlas should provide an overview of national datasets with a link to direct users to existing national CO<sub>2</sub> storage atlases with more comprehensive data types sufficient to support users with various needs.

### Site maturity

Many European countries have already well-established national CO<sub>2</sub> storage Atlases; for example the [Norwegian CO<sub>2</sub> Storage Atlas](#) created by Norwegian Petroleum Directorate (NPD), the online [CO<sub>2</sub>Stored](#) database operated by BGS (UK), the [North Sea Energy](#) CCS atlas for The Netherlands and the [CO<sub>2</sub> Storage Atlas for Spain](#). Several CCS relevant databases at European level / multi-national level are available or will be soon available, including [CO<sub>2</sub>StoP](#) to be hosted by the EC Joint Research Centre, and the [Nordic CO<sub>2</sub> Storage Atlas](#) that is already available and operated by GEUS (Denmark). These examples demonstrate the large amount of effort already invested in gathering and publishing the CCS data by many organisations serving different purposes<sup>9</sup>. However, not all of these databases are continuously updated after projects are completed or are not publicly available. Methodologies used for these databases require reviewing because, due to their differences in data availability and thus scale and applied methodologies, they may not be in line with current standards (e.g. ISO 27914 published in 2017) and methodologies. In summary, most of the candidate storage sites in the existing databases are likely to be at low Storage Readiness Levels<sup>4</sup>.

Where possible, the geological data should be of a sufficient level of detail for a cost model (such as the FE/NETL CO<sub>2</sub> Saline Storage Cost Model; NETL, 2017) to be applied to it so that an assessment of storage costs can be produced. It may not be possible to include all the required data due to confidentiality (for hydrocarbon fields) or data not actually having been acquired (in the case of an unexplored sites or regions) but geological risk data, where available, should be included. The geological risk data might include, inter alia, the number of wells (active, suspended, abandoned), density of faults, proximity to other structures / facilities / types of land use and other high-level characteristics that might require further detailed assessment.

### Capabilities

The Atlas portal should give, at minimum, an overview of European geological CO<sub>2</sub> storage sites and storage capacity. It should also have general geographical and geological information, CO<sub>2</sub> emission sources, transport infrastructure (e.g. existing pipelines and well infrastructure, port facilities), and other information

<sup>9</sup> CGS Europe report 2013 (FP7 EU funded project No 256725) summarises existing data from 28 European countries.



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(e.g. regulatory borders, water depths, hydrocarbon field locations, permits for other users). In addition, it could contain an up to date overview of existing data such as seismic surveys, wells, reports, etc., where this is available. Metadata describing each geological feature for CO<sub>2</sub> storage should be provided so the user can decide whether to investigate the data stored in other databases in more detail. There should be functionalities to allow a user to select and, where possible, download a subset of data from the database or from the other databases if the user has access. High-level calculations using the data and tools available in the Atlas should also be made available on the selected datasets through cloud computing. A harmonised methodology and formulae for assessing geological CO<sub>2</sub> storage capacity will be used. Estimates will be calculated for CO<sub>2</sub> storage capacity in deep saline aquifers and hydrocarbon fields. The user should be able to specify operational parameters such as pressure control by water extraction that will influence the capacity estimates.

The data for the web portal can be updated and improved regularly on a national basis by the individual geological surveys and other relevant organisations (e.g. Norwegian Petroleum Directorate in Norway and research institutes in other countries), where funding supports this. The Atlas could contribute to:

- harmonisation of CO<sub>2</sub> storage data in Europe;
- development of a webGIS system with a multilingual system to identify, access, use and reuse aggregated geographical information on geoenergy and mineral resources;
- providing services for the registration of data sets from different countries, such as the visualisation and overlay of the information layers obtained from distributed sources and spatial analysis;
- providing geological data to calculate the proportion of total storage capacity that has a certain maturity or certainty;
- making existing storage data from all countries in Europe accessible.

## Infrastructure and Operation

The Atlas portal should be operated by a European organisation which has close links with their national counterparts to acquire input from the national data for maintenance and possible future updates. The CO<sub>2</sub> storage atlas in each European country may host their own national data or this may be held centrally and will have the responsibility to prepare data according to agreed standards (e.g. ISO 27914).



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## Recommendations on Governance and Ownership

In 2016, the EC Joint Research Centre (JRC) started planning to publish the CO<sub>2</sub>StoP GIS as a web-GIS and as an atlas in book format. The original partners, CO<sub>2</sub>GeoNet and the Geoenergy Expert Group (GEEG) of the EuroGeoSurveys, (EGS – a network) planned to contribute at various levels. Once the GIS and the Atlas had been published, JRC planned to transfer the CO<sub>2</sub>StoP GIS to EGS for long term handling and update.

The European Commission Directorate General for Energy (DG ENER) has updated the plans (July 2019) and has now published only the CO<sub>2</sub>StoP database on the European Commission (DG JRC) website and thereafter to allow EGS to publish the GIS atlas via their European Geological Data Infrastructure (the “EDGI Platform”). We therefore recommend that the EDGI platform is the most appropriate mechanism for publishing the new European Atlas.



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## Recommendations on Operation

The basis for the atlas is an interactive web database server with a webGIS style front end, which is supported by the available storage data of individual country databases and a calculation engine. The atlas should include tools to analyse the data, e.g. to compute storage capacities and injection rates. The formulae for estimating capacity should be based on those developed by the CSLF. These formulae are essentially identical to those used by the US DoE Regional Carbon Sequestration Partnerships and were also used in the earlier EU GeoCapacity and CO<sub>2</sub>StoP projects.

The EGDI platform will access the current versions of national databases, where these exist and are linked to the Atlas. The storage portal software behind the platform will use a metadata catalogue to search for and provide tools for viewing and interrogating the datasets. There will also be an interface for designated maintenance operators to edit the database/tools and provide updates as storage resources advance. In order to ensure the smooth integration of national datasets, a common data specification will be used.

In addition to the online version, presentation of the new Atlas in the form of a publication, both electronic and report, will support the awareness of CO<sub>2</sub> storage potential availability in Europe and the visibility of the CCS technology as a whole. The publication could be periodically repeated, similar to the North American Carbon Storage Atlas<sup>10</sup>.

<sup>10</sup> <https://www.netl.doe.gov/coal/carbon-storage/strategic-program-support/natcarb-atlas>



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## Delivery

The following summarises a possible plan for delivery of an Atlas.

1. A user-testing exercise should be carried out on the CO<sub>2</sub>STOP atlas that has been published on EDGI to identify user improvement requirements.
2. Links to national data stores from the Atlas established. Some, but limited metadata, must be copied from national repositories and live links must be established for continuous updates.
3. An updated public version with most of relevant data and tools to be published via EDGI.
4. National CO<sub>2</sub> storage atlases to be funded by national programs and through EC programmes (e.g. Horizon Europe) for collaborative projects.
5. Pan-European atlas maintained with new data and new capabilities.

A pan-European project covering all the above-mentioned stages might be the most suitable solution to secure delivery.

The following funding sources should be explored to finance the European storage atlas. The main motivations from these funding sources are that they are most likely the owners of relevant data such as geological data from hydrocarbon activities, future users and beneficiaries of the atlas for developing new projects, R&D funding organizations for building basic infrastructure, policy makers for public communications. The development of a European Storage Atlas requires the coordination of national and European efforts in a significant programme, which secures the building and maintenance of the atlas. A piecemeal approach has previously led to inconsistent datasets and failed to provide the foundations for an integrated, coherent resource.

- EU funding, such as Horizon Europe.
  - Targeted to create an overarching pan-European instrument (project) coordinating the whole effort
  - Targeted to help support development of Version 2 of the Atlas.
  - Targeted to fill gaps and update data in those countries where national funding is limited (e.g. Baltic, Balkan and eastern Europe)
- E&P companies and OGCI (Oil and Gas Climate Initiative) – Many of the OGCI members will likely be the operator of CO<sub>2</sub> storage operations including both transport, injection and leakage monitoring, therefore represent a large user group of the Atlas. They also hold data which may be relevant to updating and improving the Atlas.
- Industrial CO<sub>2</sub> emitters and CCUS actors



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- ACT funding
- National programs
  - Where available, the national CO<sub>2</sub> storage atlas in each country should be supported by national funding or EU co-fund programs to establish national CO<sub>2</sub> storage atlas in each country up to the standard agreed for and to upload the data to the Atlas.



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## Current status of European and national atlases

A summary of the status of storage capacity appraisals for European countries is provided in **Error! Reference source not found.**.

## Summary of past European initiatives

Previous EU Framework Programme projects (such as the Joule II (1993-1995); GESTCO (2000-2003); CASTOR (2004-2008) and EU GeoCapacity projects (2006–2008)) have provided a foundation for an Atlas. However, because most of these projects utilised confidential data, it has not been possible to publish the data in the public domain. Although the subsequent CO<sub>2</sub>StoP project (CO<sub>2</sub> Storage Potential in Europe), which was initiated by the European Commission (2012-2014), is considered an important move towards a database with a consistent methodology, the low budget available prevented most countries from gathering new data, providing a complete inventory of potential storage sites and including larger data updates. Therefore, the resultant database is incomplete.

The first joint European research on assessment of CO<sub>2</sub> storage potential was performed within the project '*The underground disposal of carbon dioxide*'<sup>11</sup> and was funded by 3<sup>rd</sup> EU Framework Programme – JOULE 2 action in 1993-1995. The first estimates for possible European geological storage were reported with an order of magnitude of 800 billion tonnes of theoretical CO<sub>2</sub> storage capacity, mainly for storage in the North Sea (Holloway et al., 1996). These estimates of geological capacities were, as it was stated, 'broad-brush' numbers, but nevertheless encouraging and thus lead to further work.

The JOULE 2 study, combined with the commencement of the Sleipner project, was the inspiration for the GESTCO study ('European potential for geological storage of CO<sub>2</sub> from fossil fuel combustion'<sup>12</sup>). GESTCO was a 3-year EU-FP5 project covering eight countries, Norway, Denmark, UK, Belgium, Netherlands, Germany, France and Greece (Christensen et al, 2003).

A small part of the large CASTOR project ('CO<sub>2</sub> from Capture to Storage'<sup>13</sup>) enabled collaborative activities in the area of CO<sub>2</sub> storage capacity assessment between the GESTCO countries and some of the – at that time - new EU Member States and Candidate Countries of Central and Eastern Europe. First CO<sub>2</sub> storage potential data from the Czech Republic, Poland, Slovakia, Hungary, Romania, Slovenia, Croatia and Bulgaria were collected and integrated in a Geographic Information System. Data were collected on possible geological storage locations, such as aquifers, oil and gas fields and coal seams, as well as local CO<sub>2</sub> emission point sources. Based on the data and assumptions a first estimate of geological storage capacity was calculated proving that all the CO<sub>2</sub> emissions from point sources of the studied region could be stored in geological sites for 20 years (Scholtz et al., 2006).

<sup>11</sup> <https://cordis.europa.eu/project/rcn/4997/factsheet/en>

<sup>12</sup> <https://cordis.europa.eu/project/rcn/54394/factsheet/en>

<sup>13</sup> <https://cordis.europa.eu/project/rcn/73990/factsheet/en>



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The EU *GeoCapacity*<sup>15</sup> project (full title ‘Assessing European capacity for geological storage of carbon dioxide’<sup>14</sup>), has been the most comprehensive activity on mapping pan-European CO<sub>2</sub> storage potential so far. EU GeoCapacity covered 25 countries for which comprehensive country reports were produced, containing assessments of geological structures suitable for CO<sub>2</sub> geological storage, CO<sub>2</sub> point emission sources and infrastructure (pipeline) data. Although storage potential was evaluated on the basis of a unified methodology, the level of detail differed between countries, depending on the amount and quality of available data. The main result was a GIS-based, pan-European database of CO<sub>2</sub> storage potential. The database includes both public and confidential data and, as such, it could not be made freely available in the public domain. Project reports, publications and presentations are still available on the project website<sup>15</sup>.

In 2012-2013, the European Commission initiated a Specific Targeted Research Project titled *CO<sub>2</sub>StoP* (‘CO<sub>2</sub> Storage Potential in Europe’<sup>16</sup>) to establish a database of publicly available data on CO<sub>2</sub> storage potential in Europe (See Appendix 1 for more details). 27 European countries were covered and in most cases, EU GeoCapacity data were used, excluding their confidential data. Only a few countries provided updates, based on the developments funded at national levels. CO<sub>2</sub>StoP used an improved methodology for storage potential assessment, and a pan-European database has been produced. The database was housed by the EC Joint Research Centre in Petten, the Netherlands, and was made public via the EDGI platform in 2020.. Project results include the database, GIS and a calculation engine capable of providing probabilistic estimates of CO<sub>2</sub> storage capacity. A Data Analysis/Interrogation Tool is also available, which is able to perform calculations of storage capacity, injection rates and their stochastic analyses.

Although now over eight years old (and much of the data collated over 13 years ago in GeoCapacity), the CO<sub>2</sub>StoP database represents the most up-to-date pan-European dataset. However, it does not reflect the recent changes and updates performed on national and regional levels. Annex I provides an overview of current status of CO<sub>2</sub> storage potential assessment in individual European countries. It is evident that the level of knowledge, quality of datasets and form of presentation differ country by country, from top-level national atlases and databases (Norway, UK) to basic or even completely lacking assessments in some countries, especially in Central and Eastern Europe.

<sup>14</sup> [www.geocapacity.eu](http://www.geocapacity.eu)

<sup>15</sup> <http://www.geology.cz/geocapacity/publications>

<sup>16</sup> [https://ec.europa.eu/energy/en/studies/assessment-CO<sub>2</sub>-storage-potential-europe-CO<sub>2</sub>stop](https://ec.europa.eu/energy/en/studies/assessment-CO2-storage-potential-europe-CO2stop)



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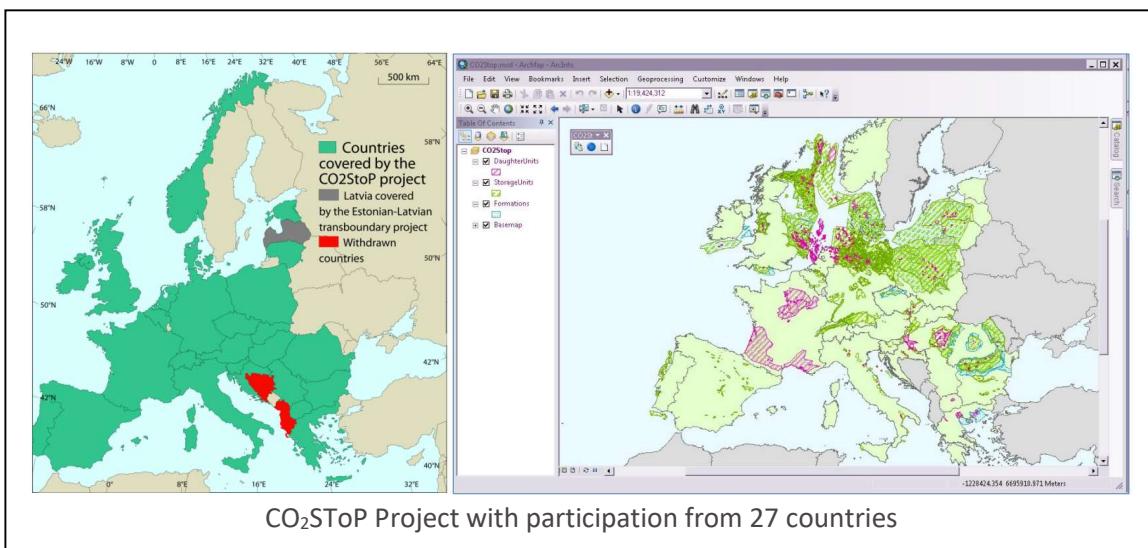
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**Figure 1:** Summary of those countries for which storage capacity estimates were updated during the CO<sub>2</sub>Stop project and an example of the high-level geological data included in the GIS.

Although not a CO<sub>2</sub> storage capacity project, the ESTMAP project also offers an indication of new data in the public domain that available across Europe since it considers storage of natural gas and hydrogen in porous media and although the storage criteria are not the same as for CO<sub>2</sub>, CO<sub>2</sub>STOP formed an important input to the ESTMAP project<sup>17,18</sup>.

## Summary of national atlases

The *Nordic CO<sub>2</sub> Storage Atlas*, available online<sup>19</sup>, was produced by NORDICCS – the Nordic CCS Competence Centre in 2011-2015; it covers Denmark, Sweden, Norway and Iceland.

<sup>17</sup> <https://www.estmap.eu/>

<sup>18</sup> <https://www.estmap.eu/downloads/ESTMAP-D3.05-v2017.01.19-Country-Energy-Storage-Evaluation-public.pdf>

<sup>19</sup> <https://data.geus.dk/nordiccs/map.xhtml>



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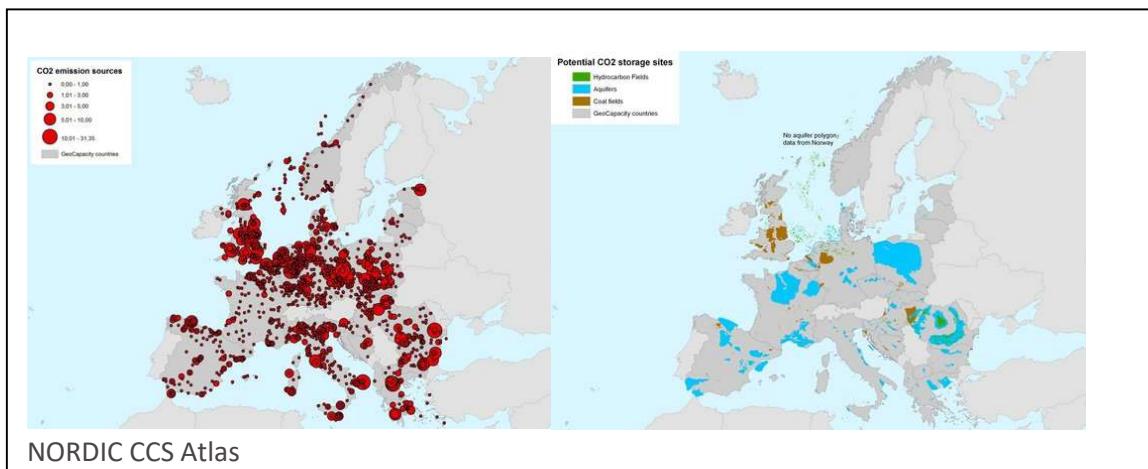
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**Figure 2:** Examples of data included within the NORDIC CCS Atlas, with European emission sources on the left and regions where CO<sub>2</sub> storage potential has been identified on the right.

The **Norwegian** CO<sub>2</sub> storage atlas was first published in 2011 for the whole Norwegian continental shelf, in 3 separate books for the North Sea area, the Norwegian Sea and the Barents Sea areas. The storage atlas is based on a stepwise methodology to arrive to the storage capacity and includes all the potential aquifers and HC fields. The digital version of the books and the shape files for the relevant data are recently planned (2019) to be published at NPDs website, free to download, no user account is required.

The **United Kingdom** national database of CO<sub>2</sub> storage information was first populated in 2011 by the UK Storage Appraisal Project supported by £3.9M public-private funding. The world-leading online UK national CO<sub>2</sub> storage database <http://www.CO2Stored.co.uk> provides free access to detailed information on more than 570 storage units. Between 2013 and 2018, The Crown Estate and The British Geological Survey developed and updated CO<sub>2</sub>Stored improving the data and functionality of the original database according to the needs of the sector. From March 2018, management, update and development of CO<sub>2</sub>Stored was transferred to BGS who host the site. Database user access and provision is supported by UK CCS Research Centre. Current work in progress is for four six-monthly database updates, starting end-December 2021. Planned developments are assignment of CO<sub>2</sub> [Storage Readiness Levels](#) to each unit, an authenticated Web Mapping Service for live GIS view most likely via the EDGI platform, and linked access to the database, for example to a proposed European CO<sub>2</sub> storage atlas.

The **Spanish** CO<sub>2</sub> storage atlas was published as the result of the work done between 2009 and 2010 by Geological Survey of Spain (IGME). The study focuses on the identification of onshore deep saline aquifers with high potential for the CO<sub>2</sub> storage and estimation of storage capacity. The map of the selected structures is completed and includes description of the regional and local geology, stratigraphic and structural



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conditions, and seal-storage formation system. There is a free online version available. Later updates, including a few offshore structures, have been provided to the CO<sub>2</sub>STOP database (2016).



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