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Executive Summary

Ove Arup & Partners Limited (Arup) and their partners Scottish Carbon Capture and Storage (SCCS) were commissioned in December 2009 by the European Commission Directorate-General Energy and Transport (DG-TREN) to undertake a feasibility study for Europe-wide CO2 infrastructures.

The purpose of the study was to develop a complete and integrated database of European CO2 sinks and sources and identify the main outline of a CO2 transport infrastructure for different scenarios. The study comprised five work packages (WP) as summarised below.

WP1 – Evaluation of storage sites

A methodology to identify and quantify the location and capacity of CO2 storage sites has been developed and applied. This is based on prior international work published in USA (Department of Energy), and in Europe, (Joule II, GESTCO, GeoCapacity. Large tonnage storage was identified in saline formations, and depleted oil or gas fields. Due to the small tonnages calculated for storage in coal seams, these were not included in the present study. A candidate storage site comprises a thick porous and permeable reservoir sandstone, overlain by a low permeability seal rock. There is no requirement that the seal should be immediately overlying the reservoir. Oil and gas fields are, inevitably, well-defined structures in the subsurface. Saline formation storage sites can be either discrete structures in the subsurface, or layers of rock extending laterally for many tens of kilometers where the limits are poorly defined. All estimates are maximum static capacities based on the total available pore space in a reservoir, and no dynamic simulations have been undertaken.

It was concluded that the GeoCapacity database was the most comprehensive and had the best internal cohesion. This study has adapted the publicly available optimistic and conservative estimates of storage calculated by GeoCapacity, to derive an auditable conservative suite of storage mass estimates. The underlying calculations and assumptions are critically dependent on generic efficiency factors linked to the definition of ‘structure’ or ‘regional’ saline formation. An auditable compilation has been made, and a uniform treatment developed across the EU 23 which were included within GeoCapacity.

Using present day emission rates of point source CO2, combined with the uniform storage estimates, a calculation was made to estimate the lifetime of storage within each member state. This clearly shows that Germany, Poland and Czech Republic are likely to have significant shortages of domestic storage within 2030-2050. Onshore storage has been assumed to be continually available from the present day, and can locally satisfy the needs of many member states. If, however, abundant onshore storage is precluded by public concern or conflicts of resource utilization with hydrocarbons or geothermal heat, then utilization of the offshore storage of the North Sea and Baltic becomes critical.

Conclusions and Recommendations

1) Abundant storage capacity is theoretically present throughout the EU predominantly in saline formations; however virtually none of this is validated to any extent.

2) Member states outwith the GeoCapacity study contain minimal additional storage, with the notable exception of the abundant storage claimed in the Scottish offshore and to a lesser extent the Baltic offshore.

3) The Ukrainian Donets basin may contain extremely large storage volumes, but is very poorly known. If this is to be developed as a potential EU option, then a much greater level of certainty is required.

4) Previous studies have published insufficient information to enable replicate calculations of storage to be made. Enabling greater visibility of the storage locations, calculation methods, assumptions made and, if possible, the basic data is essential to build confidence. To enable replicate calculations the basic data requirements are: reservoir thickness, reservoir areal extent, thickness, depth (pressure limit), temperature (CO2 density).

5) Several member states in the centre of Europe, notably Germany, Poland, Czech Republic, may experience shortages of domestic storage. Long distance transport between states may be required. Other member states are likely to have significant domestic mismatch within country between CO2 arising and storage locations. If onshore storage is limited by public opinion, then long distance transport will certainly be required to offshore sites.

6) A more publicly accessible database with improved spatial and subsurface stratigraphic (rock layer) resolution, would become a strong EU asset, to enable public understanding, business scoping and governance planning.

WP2 – Developing a coherent database of CO2 sources and storage sites

Results of previous EU studies have been examined to understand the basis of storage capacity estimates. Specific alterations have been made, only if required, to produce a simpler and more standardized common approach.

The results of this study have been displayed as 50x50 km squares, using a Universal Transverse Mercator (UTM) projection of an existing European standard, grid. The storage capacity within each grid square is the summation of regional saline formations, individual structures, and hydrocarbon fields. This is represented as a single point in each grid square centre, and is sufficient for regional planning.

New work has included recently calculated storage assessments from Ireland, and the North Sea offshore of Scotland which demonstrates a very large potential capacity. New work has also calculated first estimates for 4 EU member states; has refined estimates for the Balkan states; has made first estimates for the offshore Baltic Sea, and has made a preliminary estimate for the Donets basin of Ukraine. GeoCapacity estimates for Germany have been recalculated using basic information from geological structures, to produce a greatly improved representation of the spatial spread of storage. Because the sources of information vary greatly in quality across Europe and surrounding states, a map of estimated data quality, using the same EU grid, has been produced, as a measure of confidence.

Conclusions and Recommendations

1) An improved database of storage is essential to make further progress.

2) Upgrading the current storage database and the creation of a GIS based interface could occur in two stages:

> a) Initially a 'preliminary GIS' based on published information, could be created. Although this could be collated in a short time scale and at a relatively low cost, the preferred resolution of data is unlikely to be harmonised throughout. Although the 'preliminary GIS' may contain limited technical detail, it would still provide a resource that would substantially improve the presently poorly defined display of saline formations, structural traps and hydrocarbon fields.
>
> b) A 'simple GIS', informed by a more comprehensive database could be created if access was granted to a currently inaccessible underlying dataset. Not only would this allow storage data of a higher resolution to be provided for a greater European wide geographical coverage, but would contain interpretations derived from fundamental data using known and cited methods, which can be audited by other users. Along with accurate shapefiles for both saline formations, storage structures and hydrocarbon fields, the GIS could be populated with additional data layers such as; qualitative assessment of data quality, subsurface storage of methane gas etc.
>
> Data input into the GIS could be completed progressively, state by state, commencing with the accurate and accessible. To enable confidence in the 'simple GIS' the database would not only have to be maintained and kept up to date, but be auditable with an extent of transparency in the technical assumptions made for storage capacity estimates.

3) A database of future sources is entirely dependent on the future scenarios adopted (see WP3). These scenarios typically look at a country level and a number of assumptions need to be made to identify the future location of sources.

WP3 – Scenario development for future CO2 capture quantities

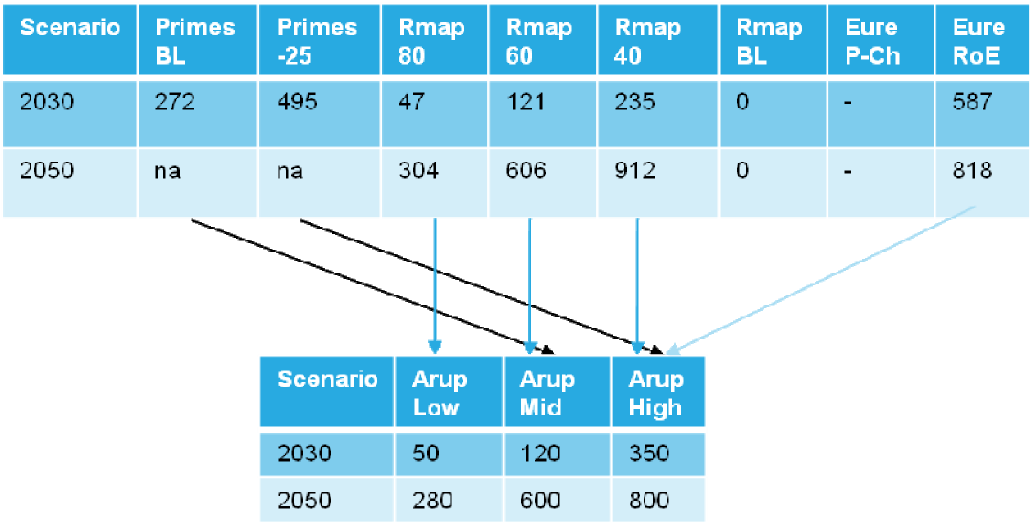
In order to develop future scenarios for CO2 capture quantities, nine existing scenarios were reviewed using criteria including geographical coverage, type of sources included, and granularity of data.

Arup reviewed the following scenarios, identifying advantages and disadvantages of each:

- EU27: Baseline 2009 (Primes Ver. 4 Energy Model)
- EU27: -25% Domestic (Primes Ver. 4 Energy Model)
- Eurelectric "Role of Electricity" scenario
- Eurelectric "Power Choices" scenario
- European Climate Foundation Roadmap 2050 scenarios (four)
- UCL/SENCO Low Emission European Energy Scenarios

From these, three future scenarios for CO2 emissions were developed, representing high, medium and low CO2-capture scenarios. CO2 capture quantities were quantified for all three scenarios at each of two design horizons, 2030 and 2050, leading to six datasets.

Mapping of scenarios analysed to the Arup CO2 capture scenarios is illustrated below, with Europe-wide CO2 capture quantities expressed in MtCO2/yr.



Scenario	Primes BL	Primes -25	Rmap 80	Rmap 60	Rmap 40	Rmap BL	Eure P-Ch	Eure RoE
2030	272	495	47	121	235	0	-	587
2050	na	na	304	606	912	0	-	818

Scenario	Arup Low	Arup Mid	Arup High
2030	50	120	350
2050	280	600	800

For each of the six datasets these annual CO2 capture quantities were then allocated to individual 50x50km grid squares using a 3-step process:

Step 1 – Europe-wide quantities were sub-divided to individual countries, based on allocation factors derived from the CCS predictions for countries and/or regions within the scenarios reviewed.

Step 2 – The disposition of existing major CO2 sources throughout Europe was assessed, based primarily on the location of existing major CO2 sources, but tempered by consideration of future site location drivers including the remaining asset life of existing sources, plans for new large CO2 sources, proximity to fossil fuel sources, and proximity to CO2 storage sites.

Step 3 – Geographical distribution of country-specific CO2 capture sub-totals, allocating CO2 capture quantities to the constituent 50x50km grid squares within each country.

Conclusions and Recommendations

1) A database of future CO2 sources is relatively easy to construct, but the data contained therein is entirely dependent on the assumptions used when developing future scenarios, particularly regarding energy demand and the mix of different energy generation sectors.

2) The location of large CO2 sources in the future is also uncertain, though can be based largely on the location of existing large CO2 sources.

WP4 – Outline of the core CO2 transport infrastructure

For the purposes of WP4 it was assumed that pipeline infrastructures represent the most likely and preferred option for transportation of CO2.

The objectives of WP4 were to:

- Determine the most appropriate design strategy for the pipeline network geometry needed to connect CO2 sources and sinks.
- Determine what geographic extent and typical pipeline routing for the CO2 collection network
- Identify an outline (or 'blueprint') for an approximate cost effective network
- Determine typical pipeline sizes and lengths for the selected network at two time horizons and derive approximate costs for each

A full hydraulic model was developed to define pipeline networks that match sources to sinks. The updated and extended databases of CO2 storage sites and the six datasets of CO2 capture quantities derived from WP1/WP2/WP3 formed the principal inputs to the model. It is clear that the quantities and spatial distribution of sources and sinks dictate the overall pipeline extent, geographic spread and inter-connectedness.

Other input data included an economic cost model for CO2 pipeline construction (using published International Energy Agency data), CO2 density (assuming CO2 in its supercritical dense phase), design velocity (2 m/s) and design life (25 years).

An initial pilot study was undertaken on a small dummy network to test a range of different network types, to identify the potential cost penalty for varying degrees of flexibility and security of supply:

- Trunk mains
- Trunk mains and gathering systems
- Ring main (looped system)

It was concluded that ring mains tend to cost around twice as much as a trunk main alternative, so we proceeded with hydraulic modelling using a network strategy comprising local gathering of CO2 within broadly-defined clusters, and trunk mains between clusters where required.

For each CO2 capture scenario, optimisation algorithms were used to search for the lowest cost pipeline network that ensures the entire source CO2, over the 25 year design life, is transported to one or more of the available sinks. The pipeline optimisation process guarantees that all sources are used but only those sinks that provide the least cost solution are utilised.

The hydraulic model successfully identified pipeline networks that satisfy this objective, and outputs from the six CO2 capture scenarios were exported to the GIS for visual representation.

Conclusions and Recommendations

1) For 2030 emissions the results illustrate a transportation infrastructure dominated by the use of onshore aquifer storage, comprising a high number of simple 'A to B' pipelines, some small-scale networks that are not complex and one significant integrated network in central/northern Europe. To accommodate increased emission sources in 2050 the network needs to be more extensive, this reflects both the larger predicted quantities of CO2 captured, and new sources that begin producing CO2 after 2030.

The total pipeline lengths and installation costs for each scenario are summarised as follows:

Scenario	Total Length (km)	Total Cost (€m)
2030 Low	6879	2074
2030 Medium	9719	4011
2030 High	12384	7592
2050 Low	11775	6785
2050 Medium	14334	10901
2050 High	15013	12667

The relative lack of a pan-European network is explained in large part by the abundance of onshore storage. In many cases individual countries can meet their own CO2 storage needs within their own boundaries, though some cross-border transportation is required in central/northern Europe in all scenarios.

2) For comparison, a second network modelling scenario was undertaken utilising only offshore storage:

Scenario	Total Length (km)	Total Cost (€m)
2030 Low	8971	3434
2030 Medium	10829	5747
2030 High	14908	11206
2050 Low	13746	9560
2050 Medium	18635	16439
2050 High	20041	19781

The alternative, offshore only, storage scenario results in an increase in total pipe length of between 11% and 33%, and an increase in total cost of between 40% and 65% compared with the scenario where all storage is available.

3) The network shape and extent of cross-border transportation is highly dependent on the availability/acceptability of onshore storage. This is a critical judgment.

4) The value of promoting and gaining acceptance of onshore storage could be up to €7,000 million.
5) Further analysis required to determine the most cost-effective progression in network development from 2030 to 2050. Nearly all 2030 pipeline routes are coincidental with those at 2050, but magnitude of flow increases between 2030 and 2050, and wider economic factors, suggest that early installation of networks to accommodate 2050 flows will be unattractive. The cost/risk of increasing capacity at a later date could be mitigated by planning for double-width wayleaves at an early stage.
6) Improving the detail of the economic cost model in the following areas would improve confidence in the results of network optimisation:

- Terrain pipeline costs
- Cost of developing an injection point at a storage site (and the sensitivity of that cost to flow rate)
- Cross-border costs
- Design life
- Large diameter Vs Twinned Pipe costs

7) Offshore storage beneath the Baltic Sea is significant in all model results, particularly in the offshore-only scenario, but to improve confidence in the Baltic would require significant exploration costs. The existing model could be used to run simulations excluding the Baltic, to test the relative pipeline costs with and without those sinks and determine whether detailed exploration of the Baltic is justified.

WP5 – Making the data available in GIS

GIS has been used as a tool to manage and interpret the large amount of data handled on this project, and forms one of the project deliverables. The aim is to implement a system which provides a means to manage and distribute geographical information (GI) to all the project delivery partners as well as forming a useful repository for related documentation.

The implementation of a GIS has a number of benefits to the project including:

- Efficient access to data through a data sharing framework
- Significant cost savings through use of a central trusted information repository
- Improve the quality assurance and integrity of data
- Efficient management of future requirements.

Following the inception workshop and subsequent internal meetings, a desktop GIS was developed to store, analyse and display CO2 sources and storage sites data.

This desktop system is based on ESRI's ArcView GIS software, part of the ArcGIS suite of products. This system is function-rich and therefore aimed at specialist users within the EC Joint Research Centre (JRC) for advanced analysis and scenario development.

Additionally, a basic online (web-enabled) GIS is currently being developed by Arup using ESRI's ArcGIS Server and Adobe Flex technology, mainly for use by non-specialists within the JRC / DG-ENER client base to enable simple mapping and interrogation. This will include the same data as the desktop GIS but with reduced functionality in line with client requirements. A web based system enables wider sharing of project information enabling a common consensus to be developed.

1 Introduction

Ove Arup & Partners Limited (Arup) and their partners Scottish Carbon Capture and Storage (SCCS) were commissioned in December 2009 by the European Commission Directorate-General Energy and Transport (DG-TREN) to undertake a feasibility study for Europe-wide CO2 infrastructures. The study commenced in February 2010 and was completed in September 2010.

The purpose of the study was to develop a complete and integrated database of European CO2 sinks and sources and identify the main outline of a CO2 transport infrastructure for different scenarios.

The study was conducted on the basis of the following main Work Packages (WP):

WP1 - Development of a coherent methodology for deciding on the suitability of CO2 storage sites and for evaluating their capacity on the basis of existing studies

WP2 - Development of a coherent and complete European database on CO2 sources (for the years 2030 and 2050) and storage sites

WP3 – Development of a set of future scenarios (for the years 2030 and 2050) for CO2 emissions and CO2 captured/available for storage

WP4 - Drafting of an outline of the core CO2 transport infrastructure, matching CO2 sources and sinks for the different scenarios defined

WP5 - Actions for making the data on CO2 sources and storage sites available to all interested parties

This report has been prepared by Arup on behalf of the European Commission in connection with the study described above. It takes into account the client's particular instructions and requirements and addresses their priorities at the time. This report was not intended for, and should not be relied on by any third party and no responsibility is undertaken to any third party in relation to it.

2 Context

In 2006/07 the European Community established guidelines for trans-European energy networks (Decision No 1364/2006/EC, referred to as "TEN-E guidelines") and Regulation No 780/2007 (referred to as TEN financial regulation). These guidelines identified priority projects of common interest, including those of European interest, among trans-European electricity and gas networks. An instrument is currently being prepared to replace 2006 TEN-E guidelines in 2011.

Over the last 5-10 years there has been a growing consensus that the use of Carbon Capture and Storage (CCS) technologies will be vital in achieving greenhouse gas reduction targets, as long as a substantial proportion of Europe's energy demands are supplied from fossil fuels. The implementation of CCS projects has been increasing in number and geographical spread. To date, the implementation of CCS has been limited to pilot plants and small-scale demonstration projects, often designed to demonstrate just one or two of the technical components. The scale of CCS projects is increasing; there are currently six CCS demonstration projects in development under the European Energy Programme for Recovery (EEPR), due to be operational by 2015, which will capture CO2 from 250MW power plants. This is considered the threshold for commercial operation. These "next generation" demonstration projects include all three components of the CCS chain; capture, transportation and storage.

CO2 transportation infrastructures do not feature in the existing (2006) TEN-E guidelines.

Whilst transportation of CO2 by ship may sometimes find applications for specific projects, the use of pipelines is widely considered to be the most reliable for mid-distance, long-term bulk movement of CO2. The physical properties of CO2 differ from those of, for example, natural gas, creating some technical design issues to overcome. For example, current installations and research in the field of CO2 pipelines suggest that the most cost-effective option is to transport CO2 in dense phase above its 'critical point', i.e. above 32 degrees Celsius and above 75 Bar of pressure. This would require pipelines to operate at higher pressures than most existing natural gas pipelines, and to operate with low levels of impurities, including water, which can react with CO2 to create carbonic acid that would be corrosive to commonly-used pipeline materials.

Suitable storage sites include depleted hydrocarbon fields (principally those in the North Sea Basin) and saline aquifers, many of which are onshore. Recent studies, notably GeoCapacity (2009), have developed estimates of storage capacity which show that whilst storage capacity in Europe is plentiful, it is not evenly distributed geographically. In some cases significant emissions of CO2 are not located close to sites of significant storage capacity, which means that transportation may be required.

Some member states have less than 20 years of potential storage within their state boundaries (based on present day CO2 emissions), increasing the likelihood of interconnected networks and strategic cross-border transfers. CO2 transportation is therefore likely to be of common European interest, and is for this reason that the inclusion of CO2 infrastructures in the instrument proposed to replace the TEN-E guidelines in 2011 is considered appropriate.

3 WP1 – Establishing the Suitability and Evaluating the Capacity of Storage Sites

3.1 Aims of WP1

The practical aims of Work Package one (WP1) were to identify prior studies of CO2 storage capacity, and re-examine these studies to compile a referenced and transparent database of storage within each member state, and to increase the geographic coverage of the CO2 storage database to include all EU 27 and the Ukraine.

3.2 Assumptions

Due to the limited time availability on this project, it was acknowledged that the pan-European storage assessment would focus on synthesising and harmonising work undertaken in previous studies. The first task of WP1 involved a comprehensive appraisal of previous European-scale CO2 storage assessment projects, which were then integrated into an extensive database. Checks were made for consistency and adaptations were made when necessary. Information from new studies of capacity was included, and basic initial assessments were made for states not included in previous work.

3.3 Reviews of previous projects

CCS storage capacity work was initiated by the Joule II study funded by the EC in 1993. This produced the first specific estimates of storage capacity, focused on the North Sea and surrounding states. These numerical estimates are now considered to be overly-generalised, and have significantly guided subsequent work but are not used here. In 2003 the GESTCO project was completed. This improved storage estimates for seven states and Norway. The focus was on specific local storage traps, which were believed to be well understood, and did not undertake comprehensive assessments of individual states. Several estimates from this work have been carried forward to GeoCapacity and then to this study. The GeoCapacity project 2006-09 was funded by EU-FP6, made the first compilation of CO2 sources, infrastructure, and potential storage across 25 states (Fig 1). This included most of the onshore sediment storage, and part of the offshore North Sea and Baltic storage. This was the most comprehensive available assessment.

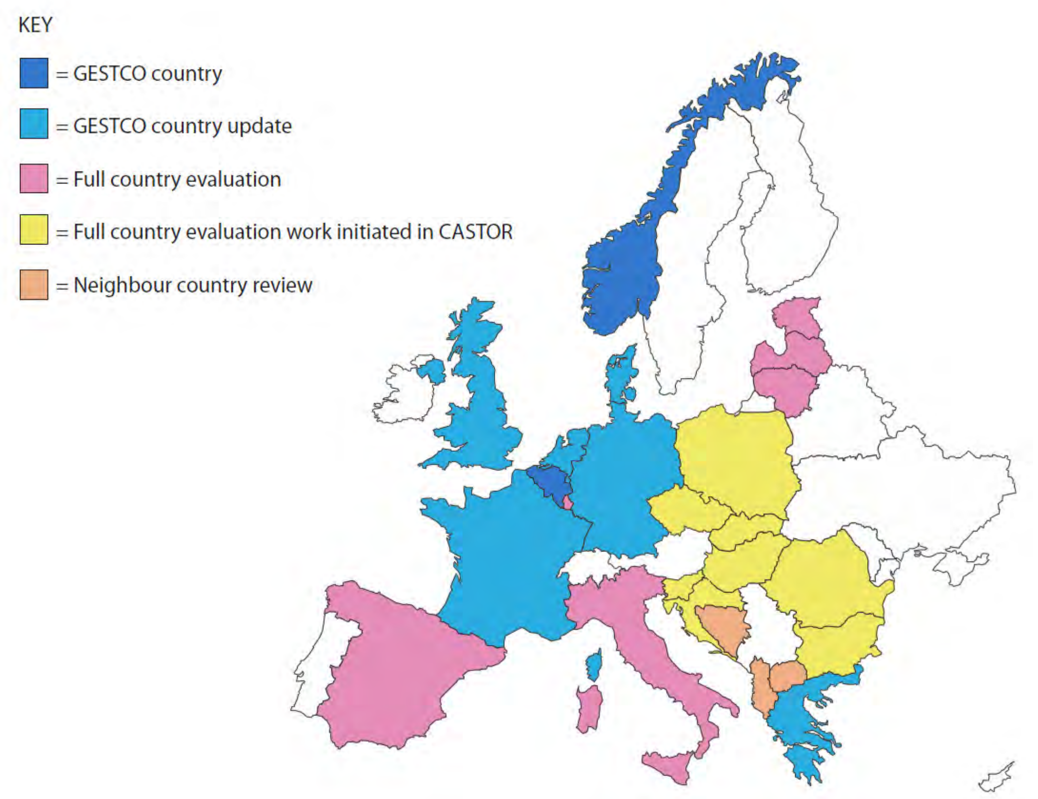


Figure 1- Map depicting countries included in GeoCapacity project- adapted from GeoCapacity

Some state assessments within GeoCapacity were based on GESTCO updates, and some on new work, which was sometimes undertaken by a neighbouring state. This inevitably resulted in different approaches in different states, focusing either on structure traps, or on storage in regional saline formations, and with diverse efficiencies of storage utilisation assumed. The resolution of published GeoCapacity information also varies from individual structures to entire states. Because of the methods of publication, technical details concerning storage locations, characteristics, and efficiencies are very difficult to discern. This severely limits transparent replication or validation of the calculations. GeoCapacity produced storage assessments using two methods, an “Optimistic” and a “Conservative” calculation. Although GeoCapacity provides a first comprehensive attempt, its database is neither publicly transparent nor auditable.

Enabling greater visibility of the storage locations, calculation methods, assumptions made and, if possible, the basic data is essential to build confidence.

3.4 A coherent methodology for evaluating storage capacity

Within this Arup-SCCS infrastructure study a database has been generated which is comprehensive, has a wider geographical coverage and is auditable, but has much less spatial resolution than GeoCapacity. This section of the report describes how that database has been developed. A more publicly accessible database with improved spatial and subsurface stratigraphic (rock layer) resolution, would become a strong EU asset, to enable public understanding, business scoping and governance planning.

3.4.1 Scoping the endowment of domestic storage

As an initial guide to the availability of storage for use across the EU, GeoCapacity estimates of storage were summarised at a state resolution. Information from the GeoCapacity database on present day emissions from CO2 point sources (derived from International Energy Agency power plant and industry data) was used to make a simple arithmetic calculation to derive potential years of storage for domestic emissions (Fig 2). This is quite distinct and different to assessing the natural endowment to store large tonnages of CO2. The input data to this map, at state level, shows that storage is abundant and geographically widespread across the EU. On a continental scale, storage exists to accept many tens of years of CO2 emissions from point sources. This map shows a great variation of domestic storage security across the EU. Some states appear to have abundant storage suitable for their domestic needs projected beyond 2060 (UK, Spain, France). By contrast, several states in central Europe (Poland, Czech Republic, and possibly Germany) are endowed with more limited domestic storage which is dominantly onshore. For CCS to be developed as an option beyond 50 years, these states may require storage outwith their political boundaries.

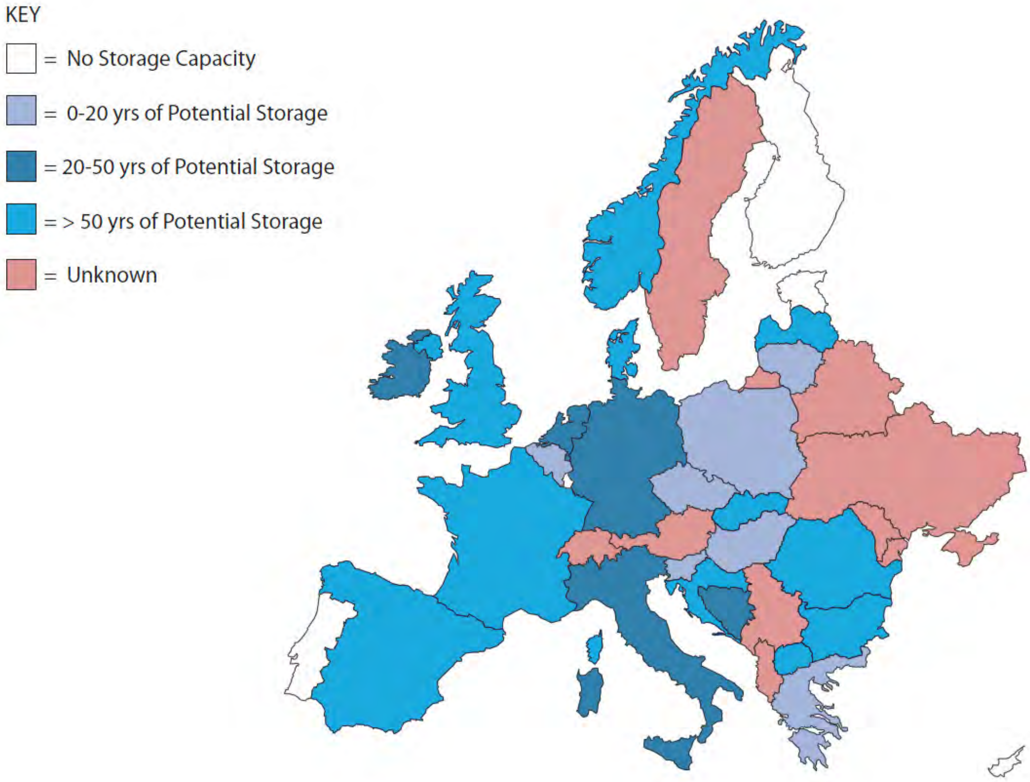


Figure 2- Choropleth Map depicting countries' potential years of storage. Storage Capacity is based on GeoCapacity 'Conservative' estimates. Emission data taken from GeoCapacity on a member state resolution

It is important to realise the limitations of this map: it assumes that onshore storage is publicly and politically acceptable, assumes that instantaneous and comprehensive CCS rollout across each state occurs, does not consider all EU 27 and neighbouring states, and also does not consider increases or decreases of CO2 emission into the future. Much more detailed scenarios are discussed later in this report. This map acts as a simple guide to identify states which may be able to offer storage, and others which may have to negotiate additional storage. Although this preliminary assessment gives an indication of a member states potential for CCS storage, it was recognised that to allow for the detailed mapping of potential CCS infrastructure, data of higher resolution would be required.

3.4.2 Detailed storage assessment

A more detailed assessment of the storage is needed, to enable strategic planning to match emission sites to specific storage with a state or outwith a state. This requires a more detailed understanding of storage location (within a structure, or within a regional saline formation, or within a depleted hydrocarbon field). Additionally the method of calculation has to be understood, to ensure comparability between different states. The most recent information would ideally be used, with estimates made for any missing states. This project set out with the aim of achieving full coverage of EU-27 plus Norway, Switzerland and the Western Balkans. Ukraine was also included, because of its perceived geological storage potential and neighbouring position to the eastern EU. To make calculations of CO2 storage in missing areas (notably Baltic Sea, Austria, Switzerland and Ukraine) publications additional to GeoCapacity were interrogated. To update storage estimates, selected recent reports from Ireland and the Scottish North Sea were particularly valuable. Each new report, and existing GeoCapacity or GESTCO report, was scrutinised to ensure a harmonious treatment using similar calculations to establish reservoir rock volume, porosity, permeability, and efficiency of storage within structures and within regional saline formations. Data compilations were made of these critical factors, at state level. A CO2 storage database was made compiled from public GESTCO and GeoCapacity data and re-worked to understand the methods of calculation.. “Conservative” estimates from GeoCapacity were used, with minor adaptation to ensure similar calculations across the current project. Consistent with the methodology used by DG Energy, the Joint Research Centre of the EC provided a 50x50 km standard EU grid, on which storage tonnages are portrayed.

3.4.3 Method of calculation

Storage capacity estimates within GeoCapacity are based on methodologies produced by the Carbon Sequestration Leadership Forum (CSLF) and represent regional or trap specific effective storage capacities. These calculations are an internationally accepted simple method of assessing “static” capacity, assuming that all the pore space of a reservoir could be utilised during infinite injection time. More sophisticated estimates are possible, using “dynamic” flow simulations with a computer model of the sub-surface reservoir. Additional overlays of engineering design for improving injection efficiencies are possible. All these types of simulation require much more information and time, so have not been attempted in this study.

Where structural or stratigraphic traps cannot be defined within a potential storage formation, capacity estimates are based on bulk pore volumes of regional aquifers. A selected efficiency is then applied to this theoretical pore volume to produce an effective capacity estimate. For structure specific traps, a storage efficiency is also applied to the estimated pore volume of a specific trap to determine an effective capacity estimate. Within GeoCapacity, different member states have usually chosen to use either the structure or the stratigraphic method. Where new calculations have been made in this project, the stratigraphic method has been used. The selection of a storage efficiency is therefore a significant decision, and one that is often highly disputed. GeoCapacity recommended storage efficiencies (SE) for both specific traps and regional capacity estimates;

Regional Aquifers:
Open/semi-closed systems; in the range between 3% & 40%
Closed aquifer systems; in the range between 1% & 20%

Specific Trap:
SE of 2% of bulk pore volume - based on work by the United States Department of Energy

3.5 Difficulties encountered

3.5.1 Inconsistent reporting

This Arup-SCCS project has used some existing published information from GESTCO, with a large amount of information from published GeoCapacity outputs, augmented by a database of storage capacity held by the Joint Research Centre, Petten, on behalf of DG Energy. A large effort was expended on ensuring that data was compatible across all states; for example that storage efficiencies around 40% were used for structures whereas approximately 2% was used for regional saline formations, without double counting.

Data publicly available from GeoCapacity was published firstly in Public Project Reports, combining both individual Work Package Reports & Final Reports, and secondly in Closing Conference Presentations – comprising both country reviews and technical overviews.

Although individual storage reports were accessible for each country included in GeoCapacity, the specific information on how capacity estimates were made varied significantly between different member states. Some countries, such as Denmark, had high data quality, with parameters given within the publishable project outputs for calculations of capacities of individual storage structures and their location. Data quality is also not consistent within member states. The southern United Kingdom has capacity estimates for individual storage structures (derived from GESTCO); the northern UK has estimates derived from regional saline formations. However, in the publishable outputs, capacity estimates were only given at a rock formation resolution.

3.5.2 Conservative/Non-conservative Estimates

Within the GeoCapacity Final Report, the potential storage capacity for each member state is summarised in tabular form. For each state there are both optimistic and conservative capacity estimates. Although optimistic and conservative estimates are consistently provided for each member state, the change factor (usually a large reduction to conservative) and the basis behind it vary significantly (Fig.3)

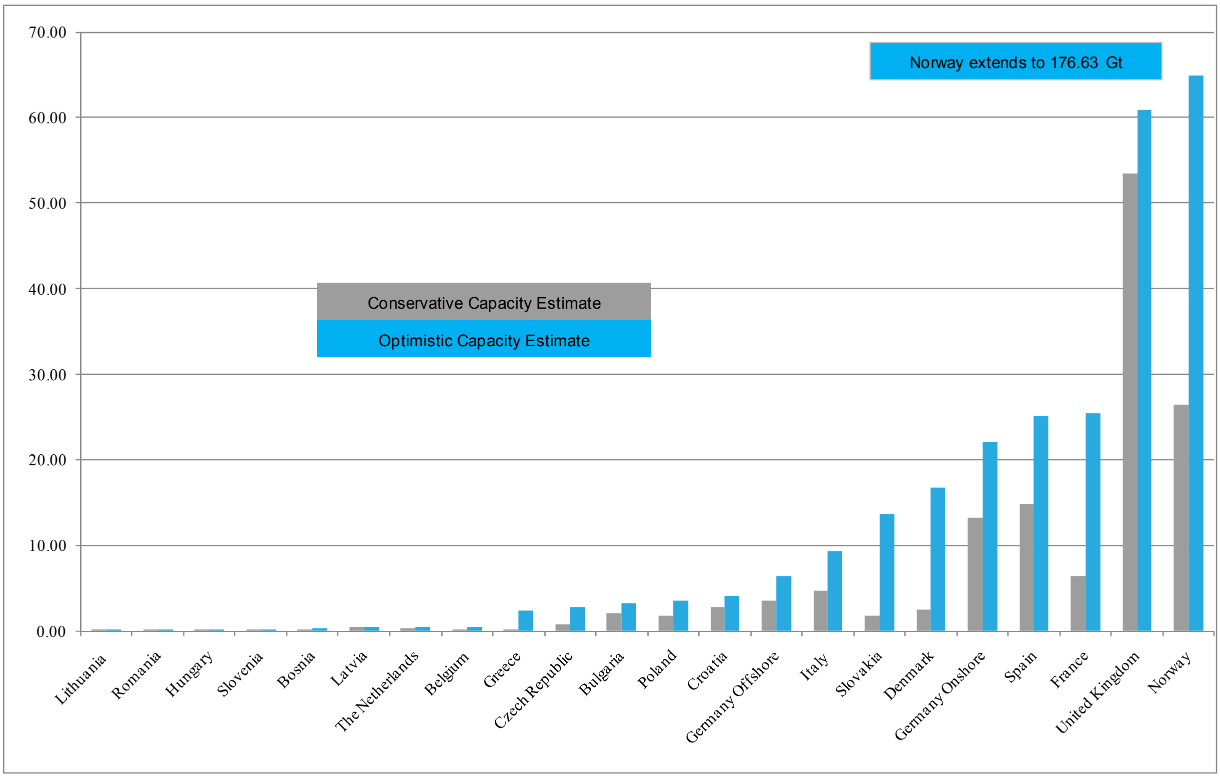


Figure 3 Analysis of GeoCapacity information shows that very large changes in estimated storage capacity were made in the conversion from “Optimistic” to “Conservative”

The basis for conservative cuts usually comes from a variation in storage efficiency (SE) used for capacity estimations in saline formations. The total storage potential is greater than 122 Giga tonnes, on a “conservative” basis. Of this, about 83Gt is offshore beneath the Scottish, English and Norwegian North Sea, and Baltic. Present EU emissions are about 1Gt/year, so that many decades of storage exists, if it can be efficiently utilised and connected. The variation in SE is not consistent between member states (Fig 4). A bimodal distribution is a consequence of assessing storage capacity as saline formations (1-2, up to 7.5%) or discrete geological structures (10 to normally 40%).

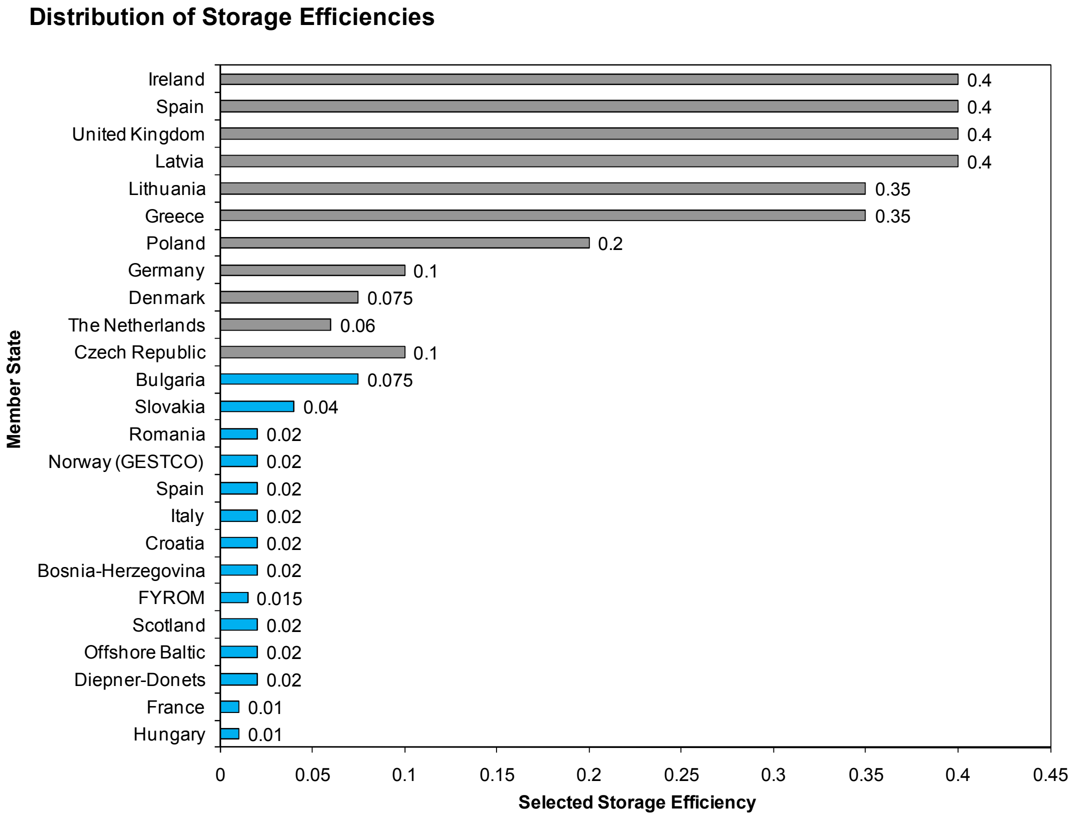


Figure 4 The storage efficiencies used by GeoCapacity as the final “Conservative” values are approximately bimodal between structures (10-40%) and regional saline formations (1-7.5%)

3.5.3 Geographic coverage of GESTCO and GeoCapacity

GESTCO focused around the North Sea, and the GeoCapacity project had a specific aim to focus on member states not included in previous CO2 storage appraisal projects. Significant geographic gaps remained when comprehensively assessing storage capacity at a European scale. This Arup-SCCS study is the first to integrate all EU member states and surrounding countries both within and outwith Europe. Countries within the study area that were not previously included in GeoCapacity are:

Austria, Switzerland, Ireland, Ukraine, Finland, Sweden, Portugal and Serbia & Montenegro.

Even within these previous studies the estimation of storage may not be comprehensive within a state. For example estimates of storage within the United Kingdom hydrocarbon and coal fields are comprehensive, whereas capacity evaluations for saline aquifers were calculated for a restricted geographic area and did not include the aquifers of the Central and Northern North Sea. Within the timescale of this Arup-SCCS project an attempt was made to upgrade capacity estimates for each member state.

3.6 Solutions and results

3.6.1 Displaying the information

To preserve confidentiality of specific information and specific localities the information from published GESTCO, published GeoCapacity and the DG-Energy database were displayed using GIS software onto a standard 50x50km grid. Fig 5 shows the distribution of storage derived from the DG-Energy database. Although storage within the DG-Energy database is based on work completed in GeoCapacity, the resolution of data has been reduced to represent only hypothetical injection points at a 50x50km resolution. These values are similar to the "optimistic" suite published by GeoCapacity, and enable a comparison to be made with "conservative" values derives from published GeoCapacity, combined with new data, new states, and adjacent sub-sea areas in Figure 7.

Important features of this display are:

- Storage data are aggregated onto 50x50km grid squares
- Data that represents hypothetical injection points are artificially consolidated to the centre point of each grid square
- Two data sets have been merged for capacity estimates in saline aquifers and hydrocarbon fields
- CO2 storage capacity estimates are optimistic values extracted from the DG-Energy database
- Capacity estimates represent the maximum likely tonnage of CO_2 that could be injected given an infinite timeframe, they do not account for injectivity

This display and associated database forms an integral part of the GIS described in Chapter 7 it can be adapted to become the foundation of a live GIS database/tool, with overlays such as: emissions now, emissions in the future, potential pipe routes, types of storage sites.

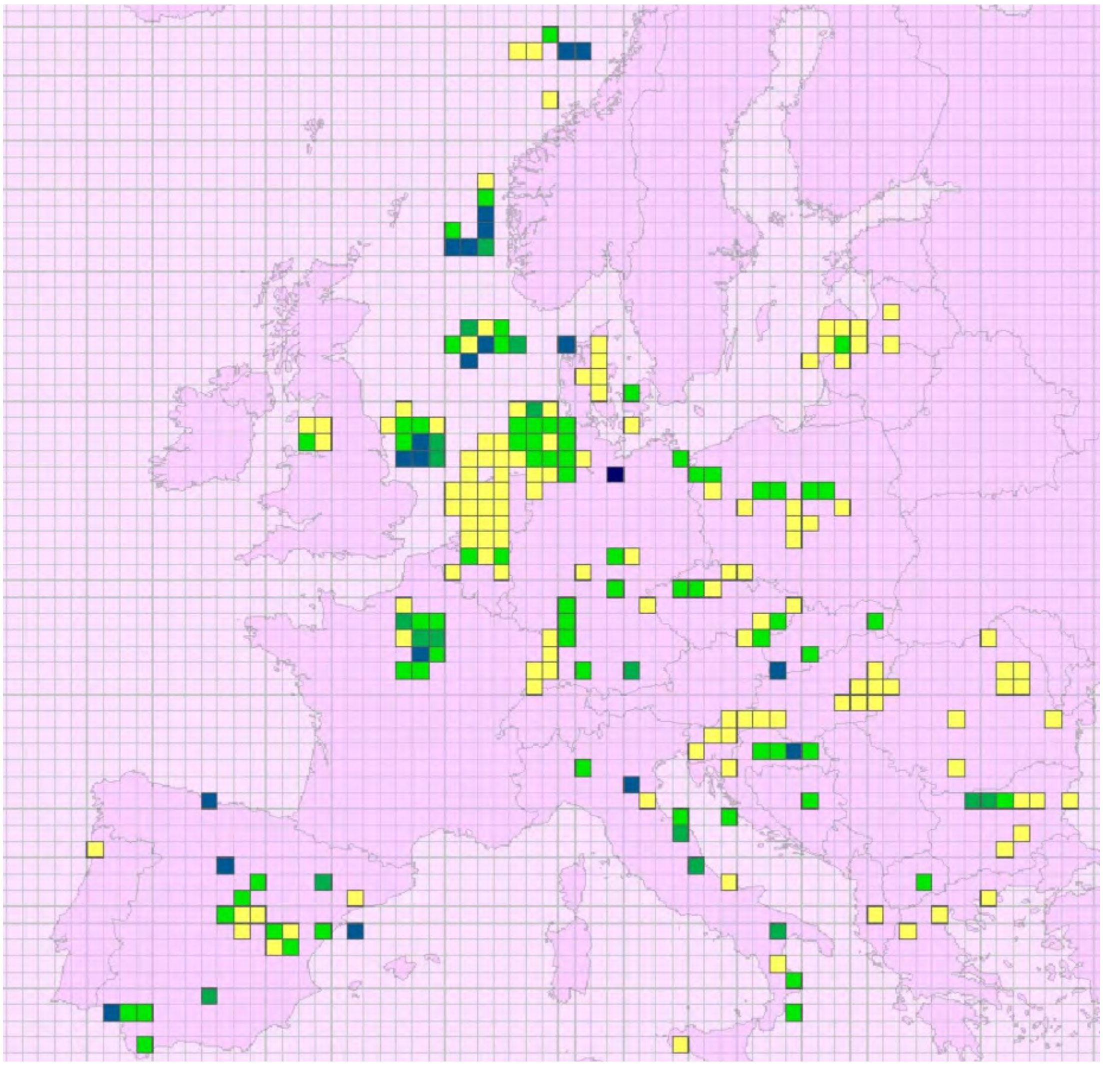


Fig 5 Optimistic values of storage capacity and locations. Key as Fig 7

3.6.2 Including additional studies and geographic coverage

Additional regions were combined into this Arup-SCCS study. Publicly available GeoCapacity and GESTCO information was added in to sense-check and extend the geographic range. Consideration was given to the application of a harmonised down rating factor, i.e. from optimistic to conservative assessments of storage capacity. It was decided that down ratings applied within the GeoCapacity framework had been based on expert geological reasoning for each State, and therefore may be more representative than applying a standardised down-rating. For hydrocarbon estimates the storage capacity estimates were not down rated.

The down ratings of saline formations were extracted from the GeoCapacity WP2 Storage Report, at a member state level. Each 50x50km polygon was assigned to a member state and the down-rating factor then applied to convert the optimistic capacity to a conservative estimate.

Additional data was included from selected areas.

Scotland: Given the area's recognised potential for CO2 storage acquiring data for this region was treated as a priority. Data was extracted from the 'Opportunities for

CO2 Storage around Scotland' completed by the Scottish Carbon Capture & Storage centre in 2009. Data for the top ten prospective aquifers was integrated into the database. Given the large lateral extent of these aquifers, consolidating the capacity onto one grid square would not be representative of its distribution Storage capacity was converted from shape files to 50x50km grids. Storage was defined as a function of area, and simply divided throughout the lateral extent of the aquifer. This region is unique in providing a large increase in previously assessed storage capacity.

Ireland: Data was acquired from the 2008 storage appraisal completed by the CSA Group. To create a harmonised storage database it was decided that only effective/practical storage capacity estimates would be integrated into the database. Therefore capacity estimates within the database may not represent the entirety of available storage capacity within Ireland. Visual gridding was undertaken as for Scotland.

Austria & Switzerland: These have no comprehensive storage assessments. Hydrocarbon field storage data was calculated from publications. The predominant regional aquifer in the region lies within the pre-Alp molasse basin that extends from western Austria, through southern Germany and into eastern Switzerland. Estimates of storage per area were extended from Germany to Austria and Switzerland.

Ukraine: This contains the hydrocarbon province of the 22km thick Dnieper-Donets basin. Very preliminary estimates were made from published basin outlines and stratigraphy. Further evaluation is needed to improve confidence in this very large possible resource.

Offshore Baltic: the onshore has good storage potential with defined large structures, so that a first estimate was made of the offshore potential. Basin area stratigraphic thickness and porosity were compiled from published work to indicate a large resource. More detailed work is needed.

North Germany: Although Germany is currently a very large CO2 emitter, and could remain so into the future, the quality of public data available on storage is remarkably poor (although detailed assessments are currently underway). Published information aggregated all the CO2 storage capacity of extremely large regional aquifers onto a single 50x50km grid square, which was very misleading. Published information enabled the identification of potential storage structures, and a redistribution of storage into multiple grid squares.

3.7 Data quality and auditability

The compilation of data, which contribute to the final assessment of storage locations across the EU27 plus Norway, Switzerland, the Balkans and Ukraine, vary greatly in quality. To provide a guide to the reliable, less reliable, and conjectural assessments a map of data quality for each state has been prepared (Fig 6). The term "High Auditability" means that sufficient information is available to identify attributes as appropriate to each member state such as: either specific subsurface structures, or the extent, thickness porosity and permeability of specific saline formations, and the efficiency ratings used to calculate total storage potential. "Low Auditability" means that some CCS storage evaluation has been undertaken, but the calculations to derive the storage values cannot be easily replicated. "First Pass" means that fundamental or basic subsurface information has been used to make an early, or even first, estimate of storage.

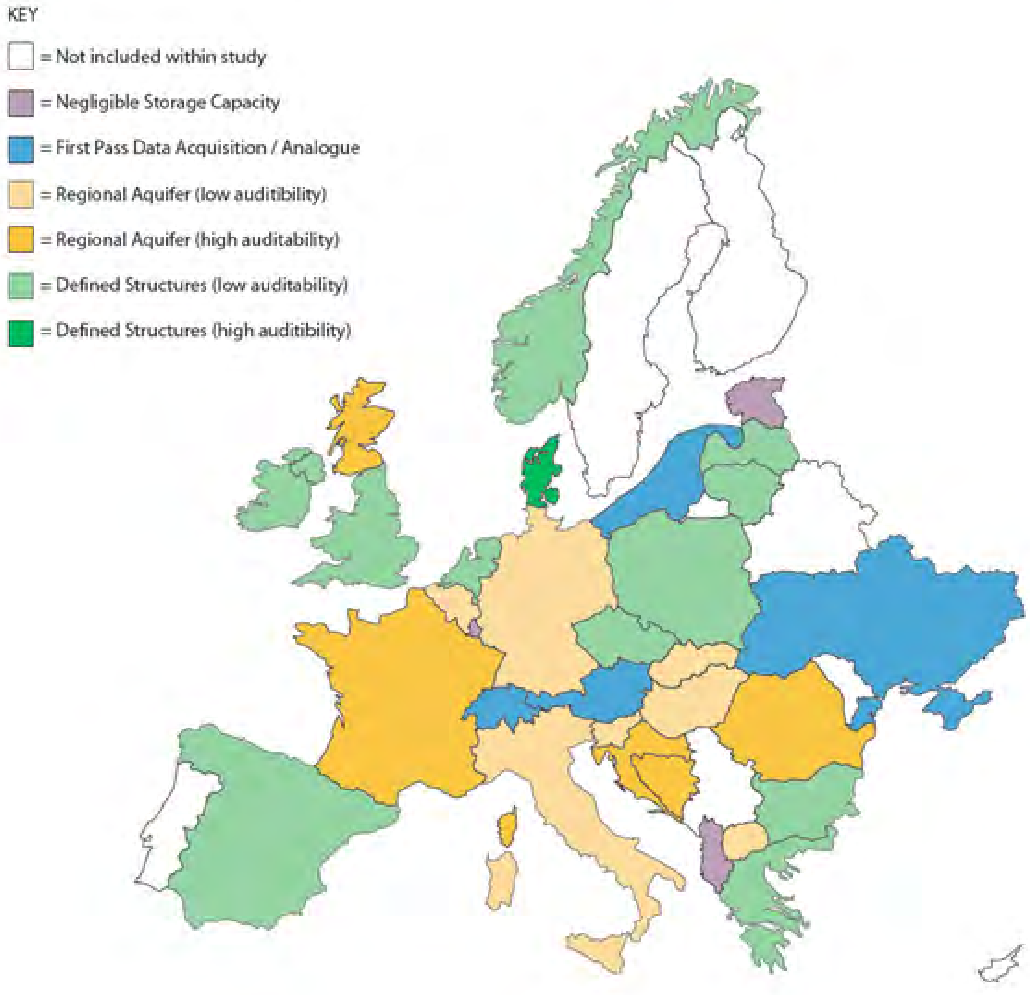


Figure 6 Assessment of data quality across the study area, demonstrating the incomplete quality of public information used to calculate storage quantities.

Note that different states have calculated their storage potential using either regional saline formations, or defined geological structures, or sometimes a mixture of both. Where a combination of the two methods has been used for capacity estimates, the method with the highest resolution is represented in figure 6.

As a final compilation, all storage sites have been arithmetically combined to produce an estimate of storage potential beneath one 50km grid square. This combines storage within depleted hydrocarbon fields, discrete structures in saline formations, and regional saline formations. Storage in coal beds, or mudrocks, is insignificant at this scale.

3.8 Recommendations

1) Due to restrictions on the use of GeoCapacity data the study output has had to aggregate data to 50km grids. It is recommended that any research and development funding of CO2 storage capacity studies by the Framework programmes, or by the Commission directly, must include a right for the Commission and its subcontractors to access and reuse the information derived from a study, although a right to publicise the fundamental detail of background information is not needed.

2) To advance into more detailed assessments of storage, then specific site-by-site calculations will be needed. These would use information such as depth, temperature and pressure to calculate CO2 density, plus salinity porosity permeability, thickness to calculate injectivity and CO2 dissolution. Member states holding significant storage capacity, and planning to use it, should be encouraged to move to this level of detail. Publicly released results will need to have some level of auditability to technical users; that means providing enough information (such as average values) so that replicate calculations can be made. The full archive of national input data is likely to remain confidential within a member state.

3) Several areas are likely to be important for offshore storage of CO2, but capacities are based on very preliminary assessments. These need to be upgraded in quality and reliability of assessment, or existing data needs to become more publicly available. Important areas include the offshore Baltic, offshore Italy, and coastal Spain. Onshore, improved quality will be needed in the Donets Basin if that is to be seriously considered.

4) It will become clear later in this report, that the CO2 transport network envisaged into the future depends critically upon the availability of onshore storage, or alternatively on the availability and development of offshore saline formations. That judgement is partly political. It is clear that investigations to de-risk the exploration and exploitation of saline formations offshore must be continued. Investigations may need to be initiated in some regions, and also include a focus on commercial and regulatory blockages. At present the capacities in this report are un-proven, and undertaking injection tests or pilot developments will improve confidence for developers.

3.9 Conclusions and summary

1) The defined project objectives have been met, and a regional assessment of CO2 storage potential has been compiled for the EU 27 plus Norway, Switzerland, Austria and Ukraine, including the North Sea, Irish Sea and Baltic Sea.

2) Potential storage is widely spread across Europe. The total storage potential is greater than 122 Giga tonnes, on a "conservative" basis. Present EU emissions from power plant are about 1Gt/year, so that many decades of storage exists, if it can be efficiently utilised.

3) The abundant storage capacity, theoretically present throughout the EU, is predominantly in saline formations; however virtually none of this is validated to any extent.

4) Several member states in the centre of Europe, notably Germany, Poland, Czech Republic, are likely to experience shortages of domestic storage. Other member states are likely to have significant domestic mismatch between CO2 arising and storage locations.

5) Member states outwith the GeoCapacity study contain minimal additional storage, with the notable exception of the abundant storage identified in the Scottish offshore and to a lesser extent the Baltic offshore.

6) The Ukrainian Donets basin may contain extremely large storage volumes, but is very poorly known. If this is to be developed as a potential EU option, then a much greater level of certainty is required.

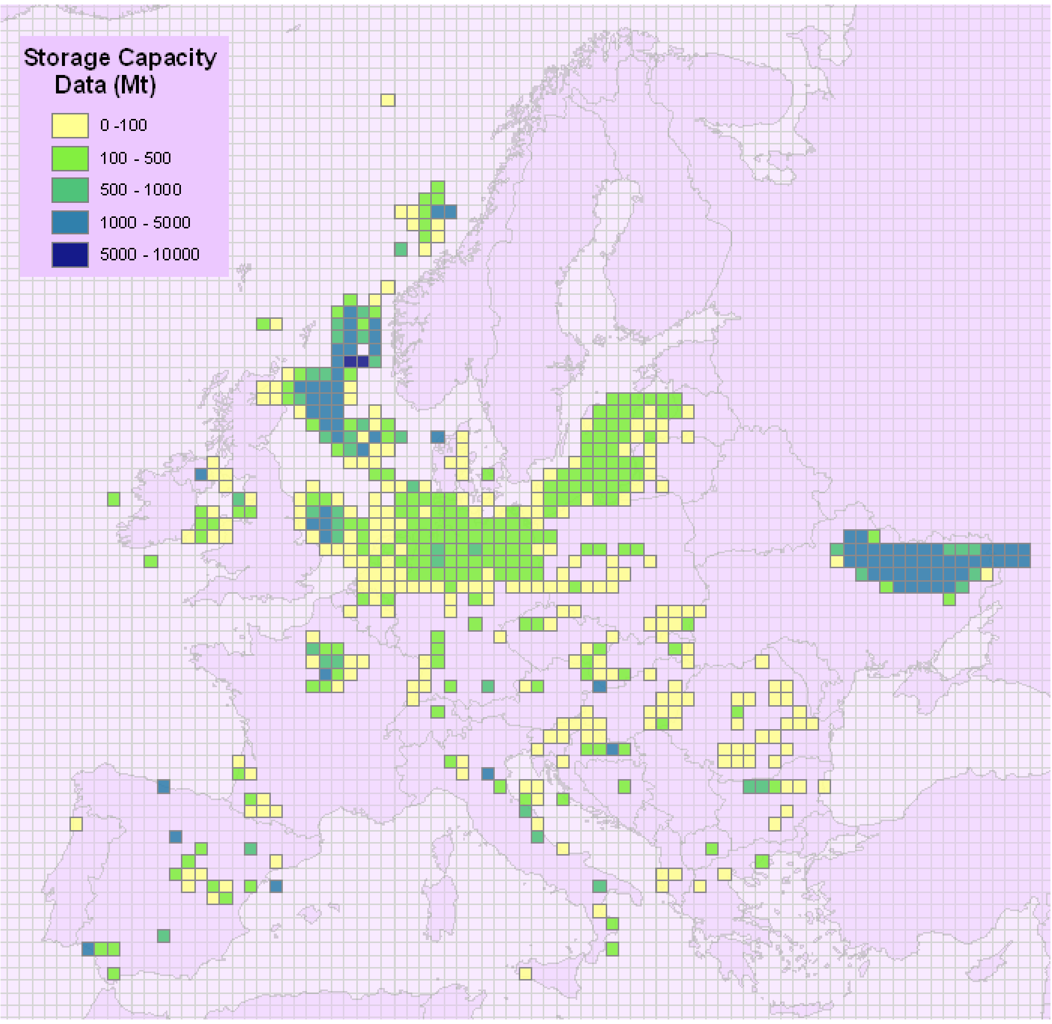
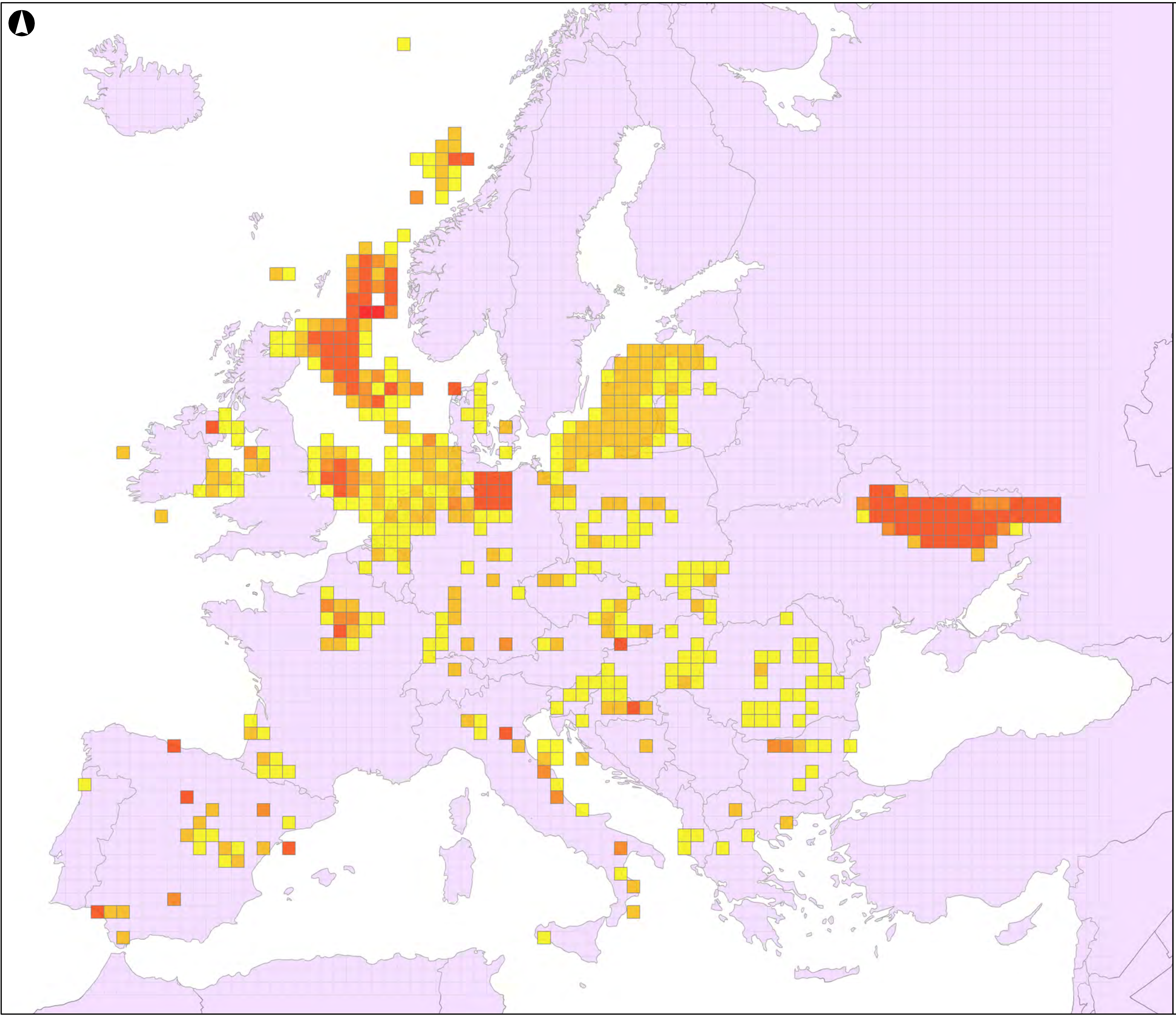


Fig 7 Final map of CO2 storage, combining published GESTCO and GeoCapacity "conservative" studies, with DG-Energy database, and augmented by new estimates for Scottish North Sea, Baltic offshore, Ireland onshore and offshore, North German distribution, Austria, Switzerland and Ukraine.



Legend

CO2 Storage in MT

🟨 0 - 100
🟨 100 - 500
🟧 500 - 1000
🟧 1000 - 5000
🟥 5000 - 10000
⬜ Europe Grid
🟪 Country Boundaries

P1	24-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

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Client

European Commission
Directorate-General Energy

Job Title

Feasibility Study for Europe-Wide CO2 Infrastructures
TREN/372-1/C3/2009

Drawing Title

CO2 Storage Sites and Volumes

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
212043-00	**OAP-CO2-STORAGE-ALL**	**P1**

4 WP2 - Development of a coherent and complete European database of CO2 sources (2030 and 2050) and storage sites

A coherent and comprehensive database of suitable CO2 storage sites has been developed during WP1, as described in Chapter 3. For the first time this gives a preliminary level of coverage across all EU 27 member states, plus adjacent nations in the Ukraine and the Baltic Sea

In WP3, development of "High", "Medium" and "Low" future scenarios for CO2 capture quantities at 2030 and 2050 has established six datasets, as described in Chapter 5.

4.1 Storage data

Storage information was gathered from the sources listed in Chapter 3. Most input was from the "conservative" version of the publicly available GeoCapacity database, after auditing and quality checking in this project. That was augmented by new estimates for the Scottish North Sea, Baltic offshore, onshore and offshore Ireland and the Ukrainian Donets Basin. Although major gaps in data coverage have now been filled, estimates often represent a very preliminary level of assessment.

The full database includes all storage, assuming that both onshore and offshore storage are equally available and acceptable for CCS projects.

Using database querying functions such as those in ArcGIS, it is easy to create subsets of the full database to represent alternative scenarios with different sets of assumptions. For example, a second database was created for use in WP4 assuming that public opinion has disabled onshore storage, so that only offshore storage is available. These are politically driven, not technically driven scenarios. There is no technical reason why onshore storage should perform to any lesser standard than offshore storage.

4.2 CO2 Source Data

Information on present-day point sources of CO2 has been derived from public IEA databases. An important aspect of this project is that present-day locations and tonnages of point source CO2 are projected into the future at 2030 and 2050. These methods are described in WP3 (chapter 5). Output from this work on future emissions is portrayed using the identical 50 x 50 km grid as that used to display storage. Consequently it is possible to directly overlay storage sites with future emission sites and, if sources and storage do not co-locate, to make assessments of transport requirements. Three emissions scenarios (Lo, Medium, Hi) are examined into the future at 2030 and 2050.

4.3 Recommendations for improving capacity estimation

1) An important missing facility for the EU is an easily accessible suite of information on the location and tonnage calculation of storage capacity onshore and offshore. This requires a web based GIS display to be created, which can be

publicly accessed. This can be tackled in two steps: firstly a "preliminary GIS" based on published information; second a "simple GIS" informed by a more comprehensive database. The guiding principles are: reliable data and auditable methods of calculation.

2) A "preliminary GIS" for CO2 storage can be rapidly created by re-working static images published by previous projects and public digital datasets. These will be converted to GIS shape files, and detail will be improved with published information around the North Sea rim, northern Germany and Poland. This approach is rapid and cheap, but contains least technical detail. Even so, this will greatly improve the present poorly defined public display of saline formations, structural traps and hydrocarbon fields.

3) The "simple GIS" will inform a regional overview of the EU. This contains interpretations derived from fundamental data using known and cited methods which can be audited by other users. Five layers of information are desirable, representing: i) political geography, ii) accurate polygon shape files of storage areas in regional saline formations iii) accurate shape files showing storage structures within the regional saline formations iv) accurate shape files showing depleted, current, and future oil and gas accumulations v) qualitative assessment of data quality. Additional layers are also possible such as sites of present day emissions, gas transport networks, subsurface storage of methane gas, electricity networks. Data input to this GIS can be created progressively, state by state, commencing with the accurate and accessible compilations already available around the North Sea from Denmark, the UK, and Netherlands. Individual states may, in addition, independently produce their own state-based GIS systems, which contain significantly more detail.

4) The best method to create a database for this GIS is to access and interpret, but not to publish, the fundamental data underlying GeoCapacity. A second method is to request donation, trade, or purchase of the comprehensive surveys made by individual member state geological organisations.

5) It is desirable to keep any GIS maintained and up to date. For example updates on saline formations from Romania and SE France are known to have recently altered, Germany will produce an onshore update in 2011, the UK will produce an offshore update in mid-2011. Staged updates to the EU CO2 storage GIS are to be expected.

6) To enable confidence in this "simple GIS" display, its continued use, and future evolution and database upgrade, it is important that information can be audited and understood by subsequent users. Information tagged to shapefiles of saline formations or hydrocarbon fields must include the criteria and methods used to define storage sites or regional geological formations, and the assumptions used in producing storage capacity estimates. Such assumptions include technical factors such as mean rock unit thickness, porosity, permeability, storage efficiency, shallowest and deepest depth, density of CO2, temperature, initial and final pressure.

7) At some future time, member states owning significant storage capacity will need to improve these preliminary assessments of "static" storage capacity, to make "dynamic" calculations based on individual sites with individual characteristics (recommendations, chapter 3).

4.4 Conclusions

1) The project specification has been met, and a basic database of CO2 sources storage capacities has been created for the EU27 plus selected neighbouring states.

2) A database of future CO2 sources is relatively easy to construct, but the data contained therein is entirely dependent on the assumptions used when developing future scenarios, particularly regarding energy demand and the mix of different energy generation sectors.

3) Information on storage capacities is not easily accessible to the public, or to technical users. A suggested remedy is to create a ‘preliminary” GIS delivered via the www and working with existing information on a crude scale of the member state.

4) Subsequently, a “simple” GIS can be progressively created and delivered via the www, for technical and/or public access, with better quality data input for each Member State as it becomes available.

5) Information must be auditable, if technical and public confidence is to be gained..

5 WP3 - Scenario development for future CO2 capture quantities

5.1 Aims of WP3

The scope of this project was to develop three future scenarios for CO2 emissions, quantifying CO2 capture quantities for all scenarios at each of two design horizons, 2030 and 2050.

It is important to note that only large point sources of CO2, i.e. those emitting at least 1MtCO2 per annum, are included within the scope of this project. The focus on fossil fuelled power stations recognises that whilst these comprise approx 35% of EU-27 CO2 emissions, they dominate large point source emissions.

5.2 Current fossil fuel electricity generation

In developing scenarios for CO2 emissions in 2030 and 2050 it is important to recognise that many existing fossil fuel generation plants will be closed and/or replaced. The drivers for this include:

- Ageing power plants with low efficiency: an examination of the existing age profile of hard coal power generation plant (see figure 8 below) indicates that by 2030/2050 the majority of will be new build, although significant existing gas plant may still be in service in 2030
- Stricter CO2 permit allocation (full auctioning)
- Environmental constraints - Large Combustion Plant Directive / Industrial Emissions Directive
- Nuclear policy (e.g. in Germany)

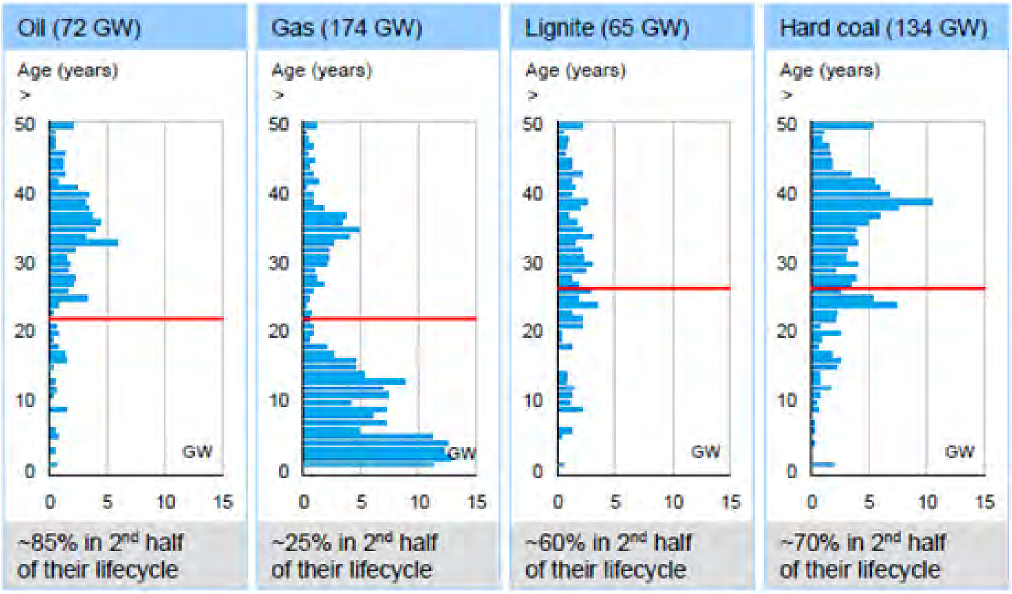


Figure 8 - Age profile of EU fossil fuel power generation

5.3 Review of existing scenarios

The approach to developing the CO2 capture scenarios for 2050 (and 2030) was to base them, where possible, on existing scenarios in the public domain. Therefore the first task of WP3 was to review these existing scenarios in order to establish their potential usefulness for this task.

The criteria for this review included:

- Geographic coverage – the focus was on scenarios that covered at least EU-25 and ideally EU-27, and scenarios that also covered geographically contiguous non-EU states.
- Scope – as a minimum, scenarios that covered the power sector (as this covers the majority of major CO2 sources and CCS developments) were needed, but the study also needed to capture other industries with significant CO2 emissions that might be candidates for CCS.
- Granularity –future scenarios were unlikely to indicate the sites of future CCS facilities, however aggregated CO2 from CCS by country was a practical ideal. Scenarios that covered particular regions within Europe (but not down to country level) were also considered.
- Age – recognising that the political and economic context has evolved over the last few years.
- Detail - for some published scenarios only limited summary findings are available and not the full scenario data

The process for reviewing existing scenarios and developing scenarios of CO2 capture from CCS sources is outlined in Figure 9 below:

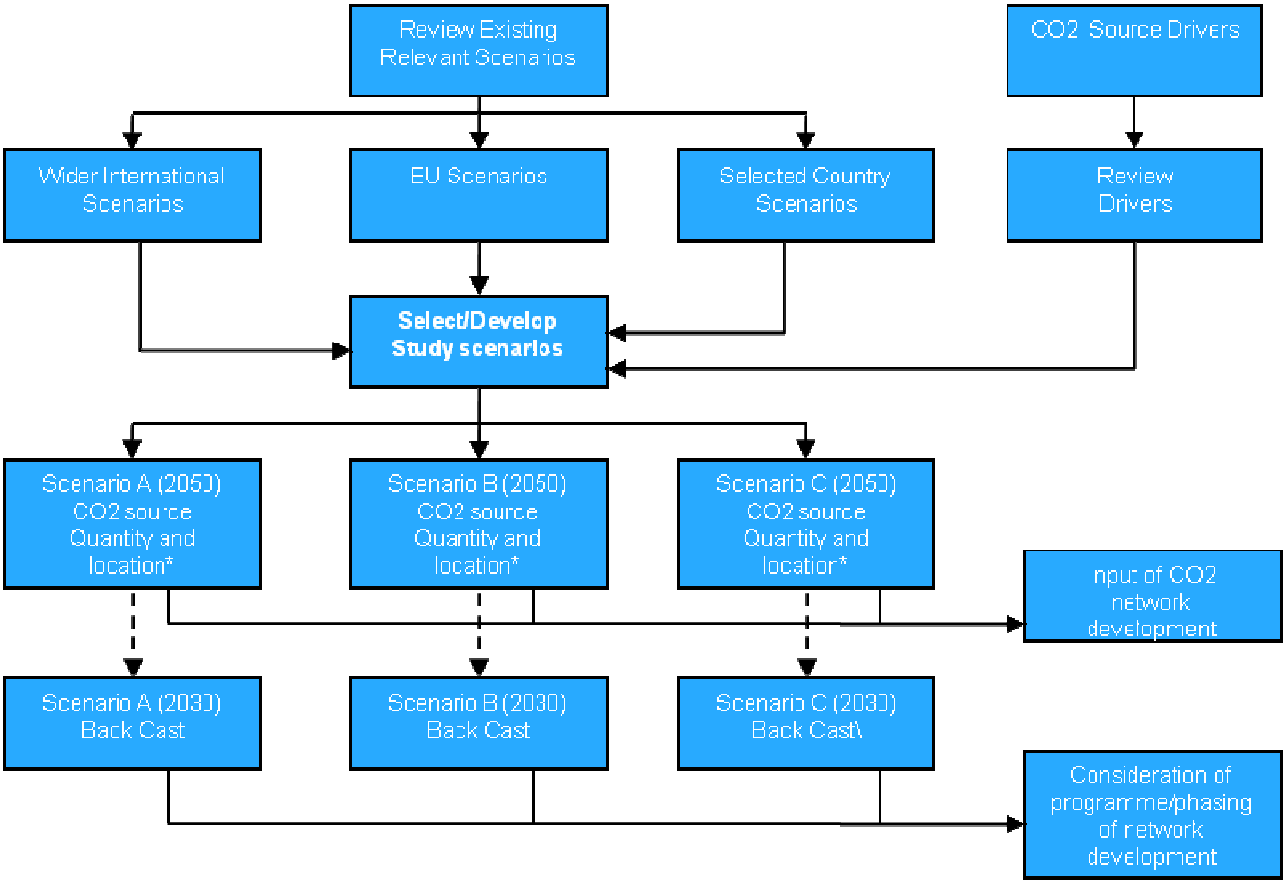


Figure 9 - Scenario Development flowchart

A key benefit of the use (or augmentation) of existing scenarios is that they are based on economic modelling and wider scenario 'storylines' that are already in the public domain, which aids communication. It also allows Arup to focus on spatial CO2 source interpretation within country and operational factors. However, for some published scenarios only limited summary findings are available and not the full scenario data. Another issue is the spatial coverage (e.g. EU-25 v EU-27 v World).

In addition, in order to derive a minimum of three representative scenarios (nominally with a high, medium and low CO2 infrastructure requirement) a larger number of scenarios needed to be reviewed as some had similarities in the likely amounts of CO2 from CCS, even though other aspects of the scenarios may differ.

The following scenarios were reviewed:

- EU27: Baseline 2009 (Primes Ver. 4 Energy Model)
- EU27: -25% Domestic (Primes Ver. 4 Energy Model)
- Eurelectric "Role of Electricity" scenario
- Eurelectric "Power Choices" scenario
- European Climate Foundation Roadmap 2050 scenarios (four)
- UCL/SENCO Low Emission European Energy Scenarios

These are discussed in turn below.

5.3.1 EU27: Baseline 2009 (Primes Ver. 4 Energy Model)

Advantages:

- One of latest EU official scenarios
- Data for individual EU-27 countries
- Covers both power sector and industry
- Data source – provided by DG-ENER

Issues:

- Scenario only extends to 2030
- Nominally a Business-as-Usual scenario (with limited CCS?)

5.3.2 EU27: -25% Domestic (Primes Ver. 4 Energy Model)

Advantages:

- One of latest EU official scenarios
- Data for CCS relevant individual EU-27 countries
- Covers both power sector and industry
- Data source – DG-CLIMA via DG-ENER
- A low carbon scenario with higher CCS

Issues:

- Scenario only extends to 2030
- Interesting differences in CCS cf. Baseline (e.g. France)

5.3.3 Eurelectric "Role of Electricity" scenario

Advantages:

- "Role of Electricity" covered EU-25 countries
- Scenario extends to 2050
- Scenario has high electricity demand and fairly high CCS expectation

Issues:

- Final report plus published supporting info and presentations were available, but unable to gain access to country by country data from Eurelectric or members
- Limited to power generation
- Published 2007 (pre recession) so see update *Power Choices*

5.3.4 Eurelectric “Power Choices” scenario

This Eurelectric “POWER CHOICES” Scenario (EU-27) assumes a 75% GHG cut across the whole EU economy with electricity as a major transport energy source. It also assumes that the CO2 price is applied uniformly to all sectors and that all power generation technology options are available (with CCS commercially available from 2025). Furthermore it assumes that there is a major policy push in energy efficiency and no binding RES targets post-2020, so that the CO2 price is the only driver for low-carbon generation post 2030. The Eurelectric “Choices” scenario has higher CCS and significantly lower nuclear by 2050 than the earlier “Role of electricity” scenario.

Advantages:

- “Power Choices” was a 2009 update of Role of Electricity
- Widened to EU-27
- Scenario extends to 2050
- Scenario has high electricity demand and fairly high CCS expectation

Issues:

- Final report plus more limited published supporting info and presentations is available, but unable to gain access to country by country data from Eurelectric or members
- Limited to power generation

5.3.5 European Climate Foundation Roadmap 2050 scenarios

Advantages:

- Three different decarbonised power sector pathways plus a 100% renewable electricity scenario
- Three main pathways all require CCS for power generation and to abate industrial emissions
- Geographical scope = EU-27 + Norway + Switzerland
- Scenarios extend to 2050 and are based on 2030 projections (PRIMES, IEA WEO 2009 & Oxford Economics)

Issues:

- No country by country data but some regional indications

The key parameters of the Roadmap 2050 scenarios are summarised in the table below.

	2010	2030	2050
Total Electricity Demand TWh	**3250**	**4200**	**4900**
TWh from CCS plant			
Roadmap 80	0	84	490
Roadmap 60	0	210	980
Roadmap 40	0	420	1470
Roadmap Baseline	0	0	0 *(2352 fossil)*

The implied annual load factors for fossil plant are ~70% for Roadmap 40, 60 and 80, falling to ~65% for Roadmap Baseline

The 40% renewable scenario yields 30% nuclear plus 30% fossil with CCS (on a TWh basis) in 2050. Of this 30%, 15% is gas (6.25% in 2030*) and 15% is coal (3.75% in 2030*) of which 9% is new coal build and 6% is the retrofit of existing coal plant. Unfortunately the scenario doesn't yield the annual CO2 captured, so this has been estimated based on typical kgCO2/MWh emission factors for coal and gas and 90% carbon capture efficiency. Note the CO2/MWh is based on hard coal and the higher CO2/MWh for brown coal has been discounted

The 60% renewable scenario yields 20% nuclear plus 20% fossil with CCS (on a TWh basis) in 2050. Of this 20%, 10% is gas (1.25% in 2030*) and 10% is coal (2% in 2030*) of which 7% is new coal build and 3% is the retrofit of existing coal plant. The method of estimating annual CO2 captured was similar to the 40% renewable scenario.

The 80% renewable scenario yields 10% nuclear plus 10% fossil with CCS (on a TWh basis) in 2050. Of this 10%, 5% is gas (1.25% in 2030*) and 5% is coal (0.75% in 2030*) of which 3% is new coal build and 2% is the retrofit of existing coal plant. Again the method of estimating annual CO2 captured was similar to the 40% renewable scenario.

The European Climate Foundation Roadmap 2050 scenario (Baseline) predicts that no CCS plant would be operating in 2050.

5.3.6 UCL/SENCO Low Emission European Energy Scenarios

These scenarios were prepared for the Swedish Environmental Protection Agency and investigated six energy strategies for the EU25. However, as the objective was to maximise renewables, under most scenarios fossil fuel generation is minimal by 2030 and no CCS development occurs. Consequently, this scenario was not considered further during this study.

5.3.7 Comment on Zero CCS scenarios

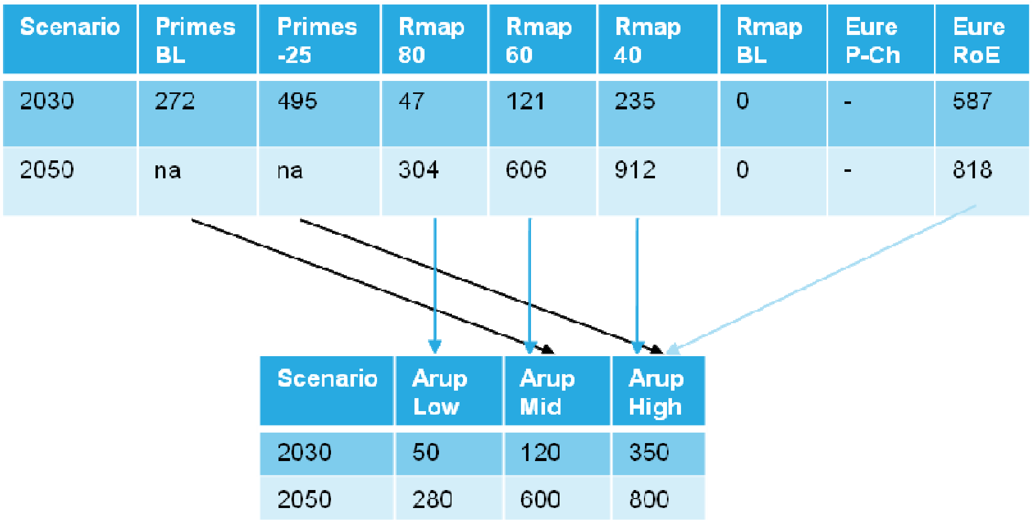
The above scenarios that predict zero CCS development in either 2030 or 2050 were not used further in this study, as by implication, the requirement for CO2 infrastructure is effectively zero. However, these scenarios should not be simply discounted, as they indicate that possible futures with minimal CCS may arise, either with continued fossil generation without CCS or with fossil generation being phased out. In such futures, investment in CO2 infrastructure would be illogical.

5.3.8 Comparisons of existing scenarios

	Primes		**Roadmap 2050**				**Eurelectric**	
	Base line	-25%	80	60	40	Baseline	Role Of Electricity	Power Choices
Total TWh/yr 2010	3313	2831	3250	3250	3250	3487	3416	3090
Total TWh/yr 2010	3313	2831	3250	3250	3250	3487	3416	3090
Total GW 2010	816	734	767	767	767	767	830	800
Total TWh/yr 2030	4170	3291	4200	4200	4200	4100	5346	
Total GW 2030	1098	1014	1393	1251	1057	967	1358	1099
Total TWh/yr 2050	na	na	4900	4900	4900	4800	6418	4800
Total GW 2050	na	na	2020	1700	1260	1110	1627	1318

5.4 Development of Arup scenarios

Figure 10 below compares the carbon captured for the above scenarios either direct from the scenario data or estimated from other scenario data. This is then mapped onto the Arup, high, middle and low CO2 captured scenarios. All data is in MtCO2/year across Europe.



Scenario	Primes BL	Primes -25	Rmap 80	Rmap 60	Rmap 40	Rmap BL	Eure P-Ch	Eure RoE
2030	272	495	47	121	235	0	-	587
2050	na	na	304	606	912	0	-	818

Scenario	Arup Low	Arup Mid	Arup High
2030	50	120	350
2050	280	600	800

Figure 10 – Mapping of scenarios analysed to Arup CO2 captured scenarios.

The Europe wide CO2 annual captured quantity was then allocated to individual 50km grid squares in two stages. In the first stage, the Europe wide CO2 annual captured quantity was sub-divided to individual countries, based on allocation factors derived from the CCS predictions for countries and/or regions within the scenarios reviewed. For some countries, for example Malta and Luxembourg, this yielded a prediction of zero CO2 captured in both 2030 and 2050, whereas some other countries captured the bulk of CO2 across Europe, for example Germany, Poland, UK and Spain.

This initial stage of country CO2 captured allocation is outlined in the process diagram shown in Figure 11.

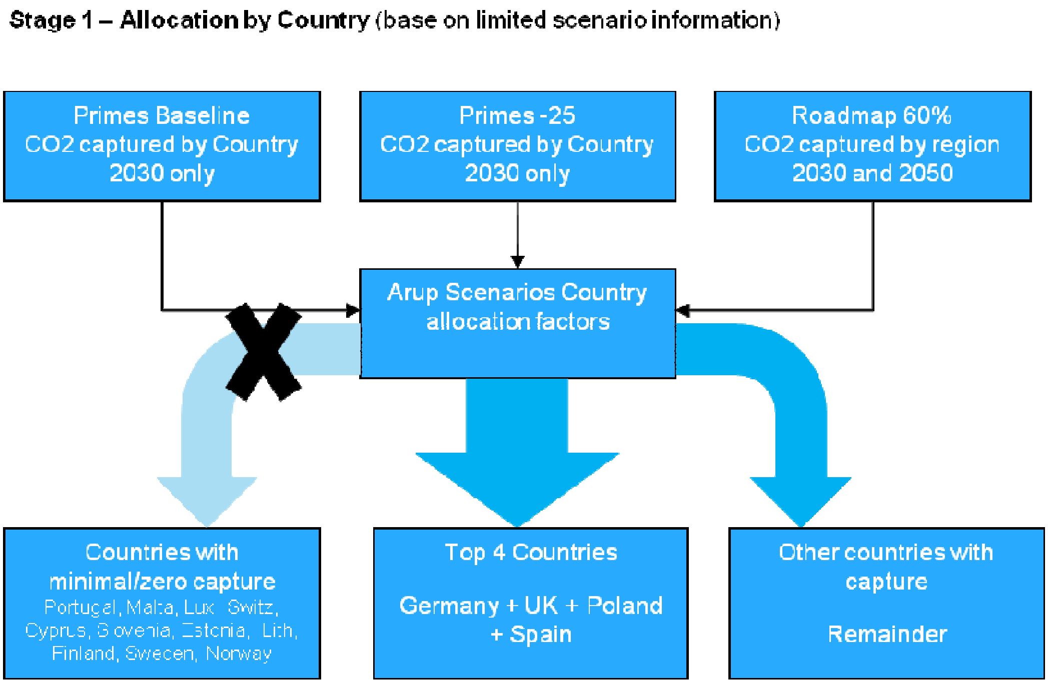


Figure 11 - Geographic distribution of CO2 captured by country

In order to assess potential CO2 infrastructure requirements the country wide data then needed to be dis-aggregated into 50km squares.

Whilst considerable data is available on the disposition of existing major CO2 sources throughout Europe, as discussed above many of the existing sources would cease operation by 2050.

The following drivers will influence the location of new CO2 source development (principally electricity generation from fossil fuels):

- Current plans for new large CO2 sources
- Future drivers/constraints for new CO2 source development, e.g. water availability
- Fossil fuel sources in 2050 (e.g. coal field depletion)

Therefore the following process was adopted in the allocation of each country specific CO2 captured subtotal to constituent 50km grid squares:

- Firstly it was assumed that CCS plants would generally not produce less than 1Mt CO2/yr. This recognises that fossil fuel power plants with carbon capture would be likely to be of significant scale and indeed this is necessary for it to be sensible to consider connection to large scale CO2 infrastructure.
- Secondly CO2 capture sites were assumed to have similar locations to existing major CO2 sources (e.g. established industrial areas). This was used as a proxy, for access to fuel (e.g. near mines) and grid, water infrastructure, site availability etc. However, this was tempered by consideration of future site location drivers – for example reflecting the desirability of more coastal sites (especially North Sea) for ease of access to imported fuel and proximity to CO2 sinks.

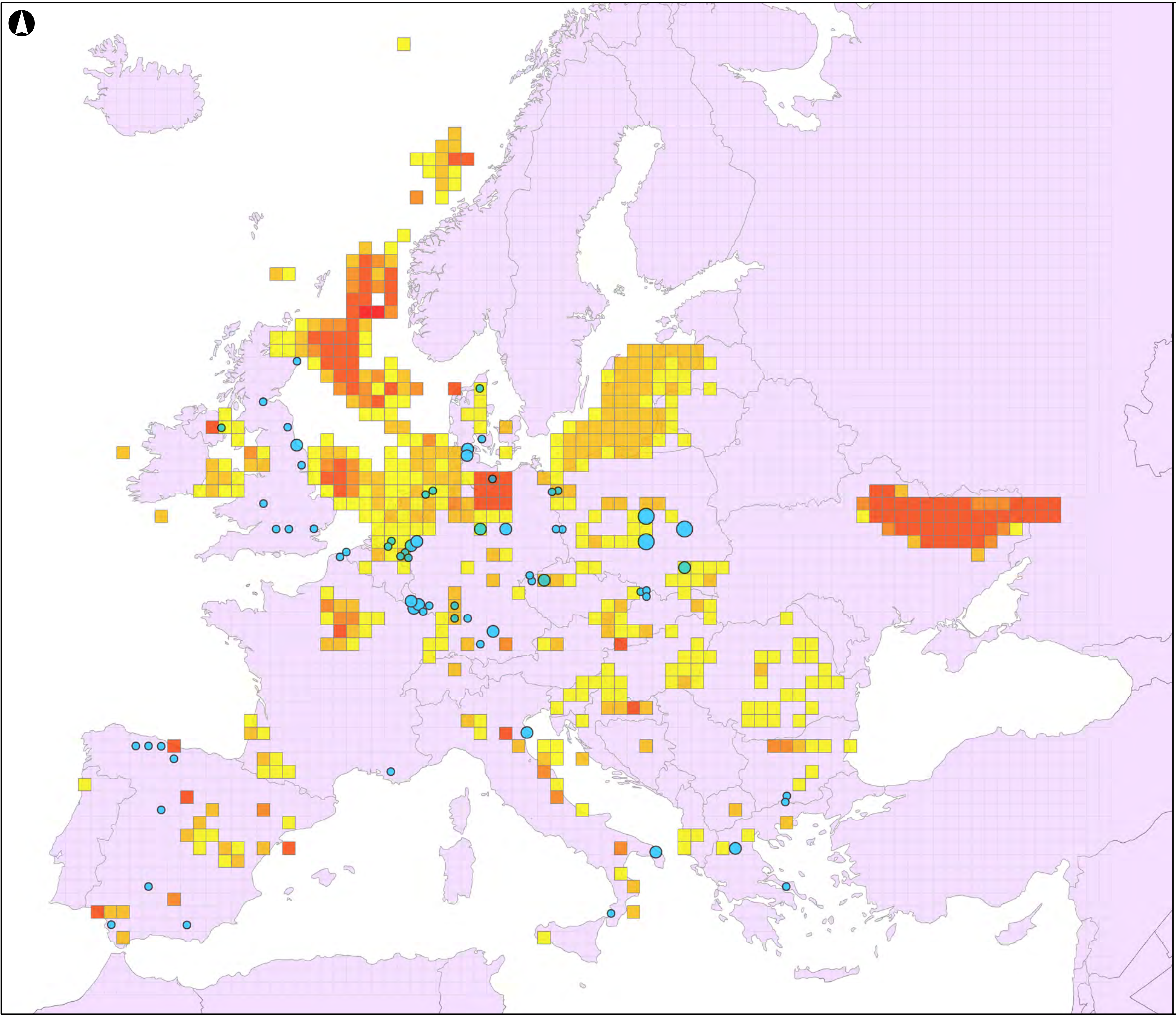
5.5 Peak vs. annual average CO2 production

Fossil fuelled power stations are expected to be the majority of future significant (>1Mt/yr) CCS CO2 sources, but as wind (or other variable renewable) generation increases, the operation of fossil generation is also predicted to become more variable (particularly in countries where hydro cannot balance wind variation) This has implications for CO2 production (peak vs annual average) – and consequently CO2 infrastructure. The study has considered how annual total CO2 production might vary throughout the year, as this may require CO2 infrastructure to be sized to cater for peak hourly or daily CO2 production. This was assessed by looking at implied plant annual load factors from scenario data.

Significant investment in new electricity generation is expected even in the next decade and more than half of this is expected to be in renewables. For example an RWE/IEA forecast for 2020 indicates 208 GW of wind, 52 GW of photovoltaic and 2.4 GW of solar thermal within Europe. Historically individual countries were able to accommodate the variability associated with significant renewables by export/import from neighbour countries, however, ambitious EU climate targets will tend to increase renewables in all countries and nuclear with limited flexibility in some countries, so the scope for export/import in future may be limited. As a consequence, more variability will have to be balanced within each country/grid area. Fossil fuelled generation is likely to play a significant role in such balancing, although there will also be an increased role for storage (e.g. pump-storage) and demand management (including electric vehicle charging) and smart grids

Therefore, in order to consider potential CO2 infrastructure options, it is necessary to recognise that CO2 production may vary from hour to hour and day to day. Some studies (e.g. Poyry-UK) indicate that fossil generation annual load factors may fall from 70-80% to 30-40% due to balancing variable renewables (wind). The Primes, Eurelectric and Roadmap scenarios indicate that after an initial reduction in load load factors upto 2030 (to ~65%) they are expected to recover to ~70% by 2050.

A3



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European Commission
Directorate-General Energy

Job Title

Feasibility Study for Europe-Wide CO2 Infrastructures
TREN/372-1/C3/2009

Drawing Title

2030-Lo CO2 Capture Scenario

Scale at A3

1:14,000,000

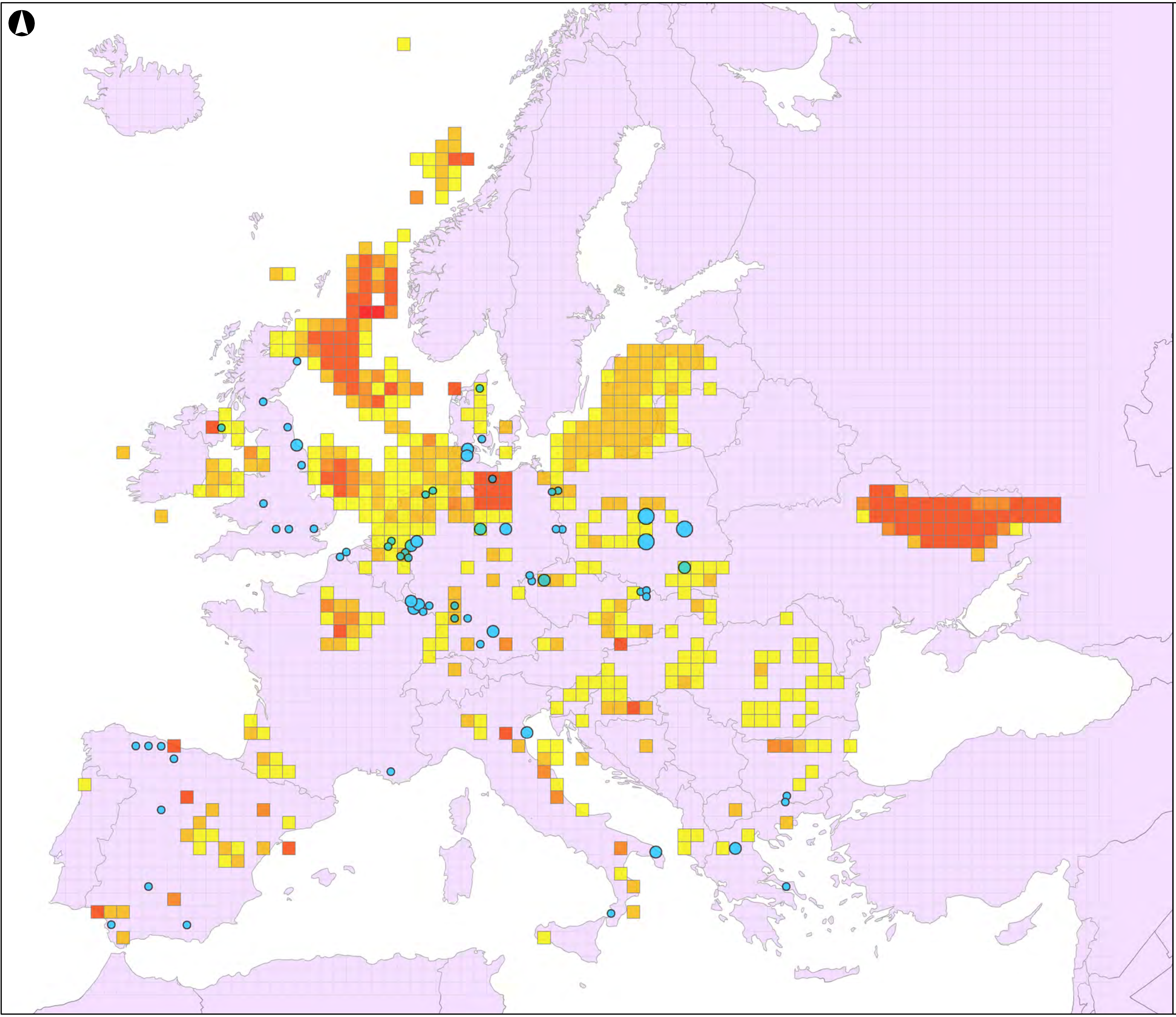
Drawing Status

For Information

Job No	Drawing No	Issue
212043-00	**OAP-CO2-CC-2030-L**	**P1**

Template A3: Version 2

A3



Legend

CO2 captured in MT/yr 2030 M

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- 🟪 Country Boundaries

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Metres

0 195,000 390,000 780,000

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Drawing Title

2030-Mid CO2 Capture Scenario

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Drawing Status

For Information

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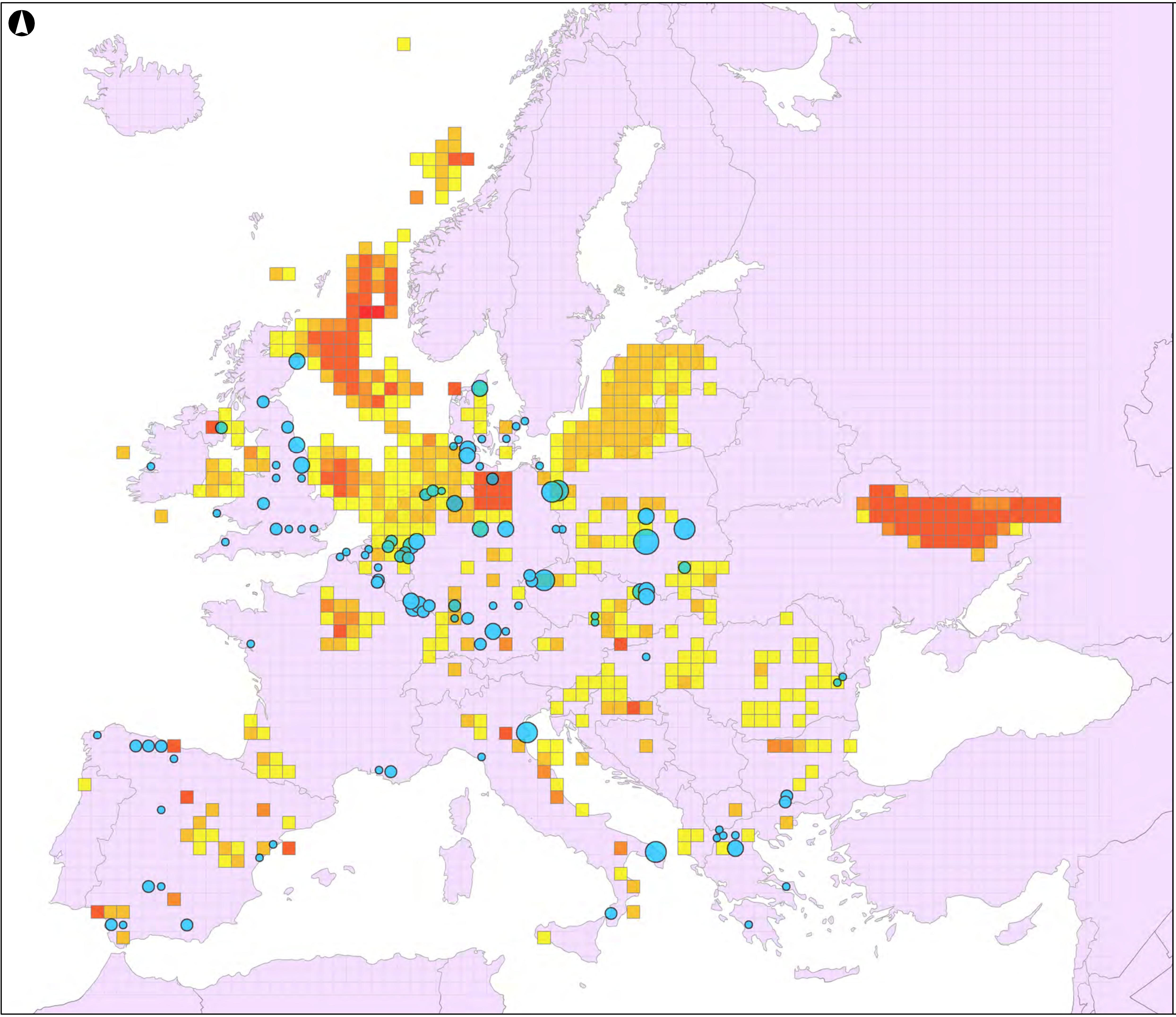

Legend

CO2 captured in MT/yr 2030 H

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- 🟪 Country Boundaries

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TREN/372-1/C3/2009

Drawing Title

2030-Hi CO2 Capture Scenario

Scale at A3

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Drawing Status

For Information

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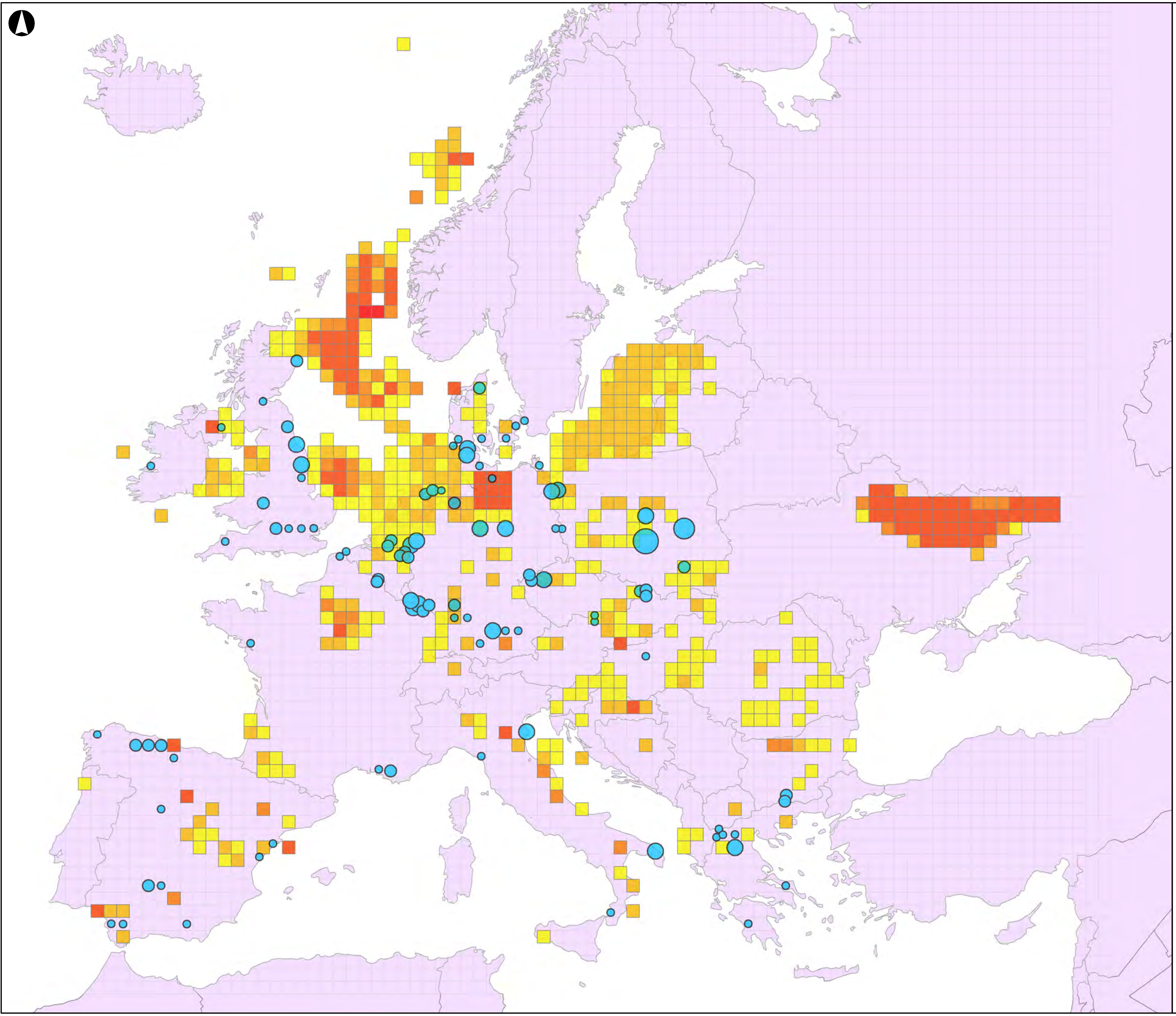

Legend

CO2 captured in MT/yr 2050 L

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ⬜ Europe Grid
- 🟪 Country Boundaries

Issue	Date	By	Chkd	Appd
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2050-Lo CO2 Capture Scenario

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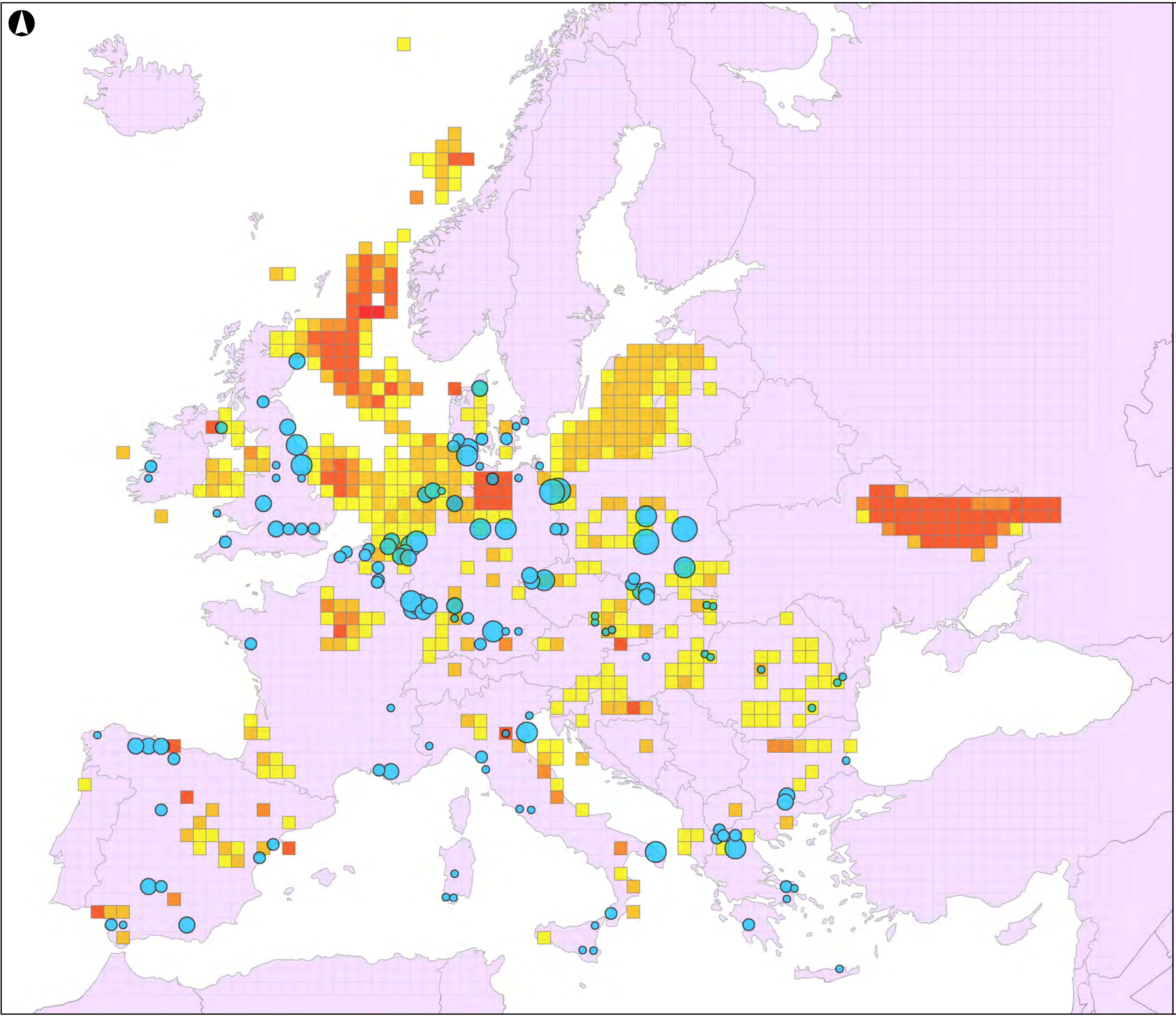

Legend

CO2 captured in MT/yr 2050 M

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ☐ Country Boundaries

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Drawing Status
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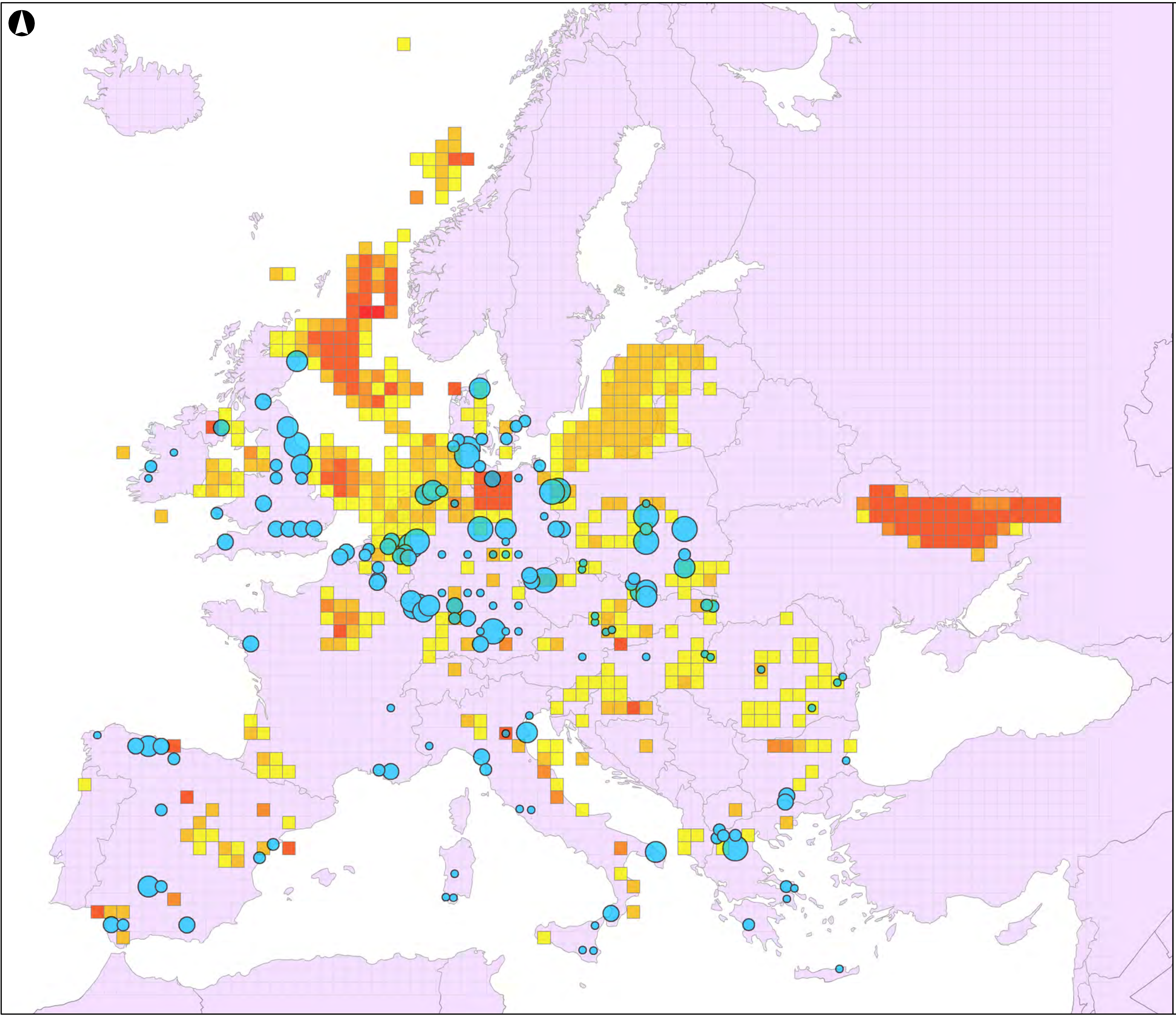

Legend

CO2 captured in MT/yr 2050 H

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ▨ Country Boundaries

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Scale at A3

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Drawing Status

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Template A3: Version 2

6 WP4 - Outline of the core CO2 transport infrastructure

6.1 Aims of WP4

The aim of WP4 was to identify an outline of the core CO2 transport infrastructure required to match CO2 sources and sinks for the different scenarios defined. This Work Package was broken down into five tasks:

- Determine the most appropriate design strategy for a CO2 collection network
- Determine what type/shape of collection network is likely to be the most cost-effective for the specified scenarios
- Identify an outline (or “blueprint”) for an appropriate, cost effective, network
- Determine typical pipeline sizes for the flow rates involved in each scenario
- Determine the total length for the selected network at two time horizons, and derive an approximate cost of transportation infrastructure for each scenario.

6.2 Infrastructure Network Strategy

In looking at the options for CCS network infrastructure three principal options were identified:

- Trunk mains
- Trunk mains and gathering systems
- Ring main (looped system)

The trunk mains and gathering system closely resemble each other in the ‘mathematical’ shape of the system, with each resembling a tree type structure. In comparison, the process industry uses ring mains where security of supply is paramount.

6.2.1 Ring Mains

In a ring main (or looped) system, one single pipe break does not disconnect any source from a suitable sink. This is shown on the figure below:

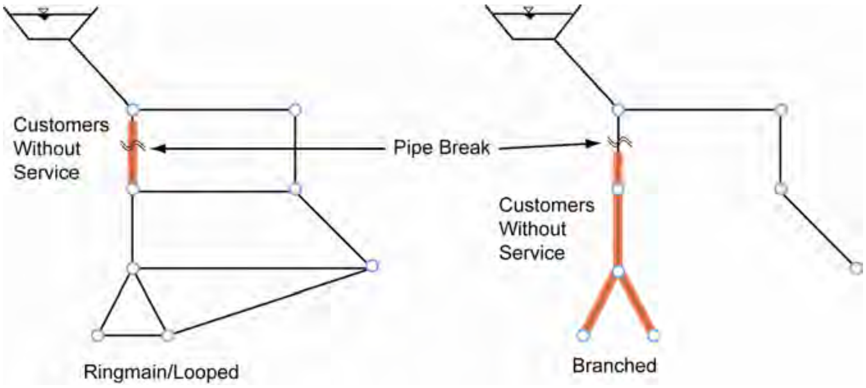

Figure 12 Security of Supply in Systems

A pilot study was undertaken on a small dummy network to test a range of different network types, to identify the potential cost penalty for varying degrees of flexibility and security of supply. Initial analysis of a simplified network identified that ring mains have a significant cost premium, potentially up to twice as much as a trunk main alternative. In the case of CCS it is probable that infrequent outages due to maintenance, repair or damage will be managed by some short-termed venting (or storage) of CO2 and hence the cost premium for a ring main approach may not be warranted. Although this initial costing exercise has not considered the potential costs of venting or storage, it is likely that the cost premium associated with a ring main system would remain significant. Therefore for the purposes of this study it is assumed that providing full security of supply would be uneconomic and that a single transportation route from source to sink would be adequate. This assumption could be reviewed if the impact of short term venting or storage is considered significant.

6.2.2 Gathering Systems & Trunk Mains

Although there is some similarity, it is useful for this study to consider that gathering systems tend to use networks of smaller diameter pipes in regions of high sink or source capacity to transport flow to the major pipelines. In contrast, trunk mains tend to comprise more ‘A to B’ pipelines.

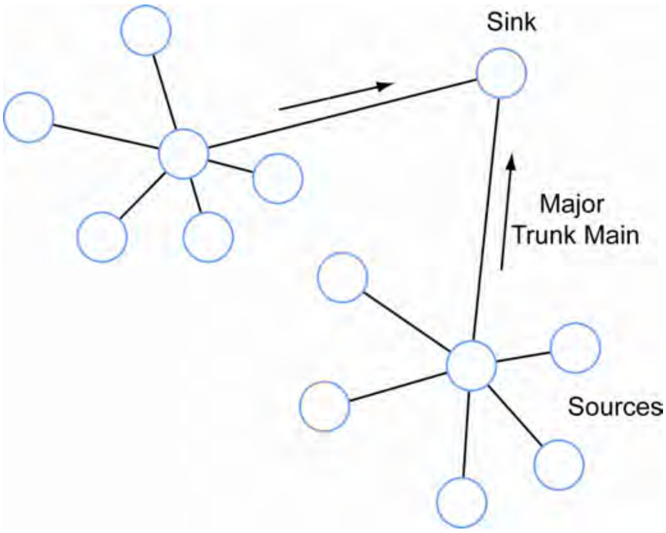

Figure 13 Gathering Systems

The optimiser was then configured to allow either ‘A to B’ style trunk mains or gathering/distribution configurations.

6.3 Input data – storage volumes and source flows

The updated and extended databases of CO2 storage sites and the six datasets of CO2 capture quantities derived from WP1/WP2/WP3 formed the principal inputs to the network modelling work undertaken in WP4.

In order to build, run and interrogate the model within the timeframe for this study it was necessary to reduce the large number of data points (597) in the database of storage sites. For the purposes of simplifying the storage dataset Arup-SCCS agreed on a lower threshold for storage volume within individual grid squares, below which storage could reasonably be disregarded during network modelling. Setting the threshold at 50Mt per 50x50km grid square omitted 250 data points (reducing the dataset to 347) but retained 98.3% of total storage identified within Europe.

Due to the lack of confidence in its storage capacity, and its location outside the core area of this study, the Ukraine Donets basin was excluded from the network modelling.

Source flows are summarised in the table below.

	Low Flow	**Medium Flow**	**High Flow**
2030	57.2	138.9	386.4
2050	307.7	667.6	871.7

Table 1 Datasets for this Study (Mt/year)

In comparison, the total storage capacity expressed in mass of CO2 is 342197 Mt, which means that at a Europe-wide scale there is between 393 and 5978 years of storage available.

6.4 Hydraulic Methodology

6.4.1 Hydraulic Models & Optimisation

Optimisation in hydraulic networks has a long history of theoretical work. Some of the earlier schemes used linearisation to simplify the hydraulics because that allows traditional Linear Programming optimisation. The optimum was ‘guaranteed’ but at the expense of simplified hydraulics.

During the last decade, evolutionary methods such as genetic algorithms (GAs) have been used extensively for the optimal design and operation of fluid distribution systems. More recently, ant colony optimization algorithms (ACOAs[1]), which are evolutionary methods based on the foraging behaviour of ants, have been successfully applied to a number of optimization problems. The findings of recent studies indicate that ACOAs are an attractive alternative to GAs for the optimal design of distribution systems in terms of computational efficiency and their ability to find near global optimal solutions[2].

The network analysis undertaken has used a full hydraulic model with an Ant Colony algorithm – a type of ‘metaheuristics’ optimiser that is well suited to hydraulic problems, especially complex ones such as a Europe-wide CO2 network. This type of optimiser is gaining impressive results in hydraulic models and offers an alternative that does not require the hydraulic problem to be simplified. This approach also allows multi-variable optimisations (such as capital vs. operating costs) which provide a future development route for the project.

The benefits of using a fully functioning hydraulic model are that it

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[1] See for example http://en.wikipedia.org/wiki/Ant_colony_optimization for an introduction

[2] Ant Colony Optimization for Design of Water Distribution Systems J. Water Resour. Plng. and Mgmt. Volume 129, Issue 3, pp. 200-209 (May/June 2003)

- Avoids unnecessary linearization or simplification
- Allows any degree of complexity, so it can be extended to include any built elements in the future and can have boosters and control added
- Can be extended to offer multi-variate optimisation
- Could be a platform for engineering design in the future

In this study, the technique is used to identify near optimum solutions to the task of developing a blueprint for CO2 transportation infrastructure around Europe. In our case, the sole optimisation criterion is cost, i.e. *the objective is to find the least cost network that links all sources to a sink of sufficient capacity for 25 years of operation (the design life)*. It is assumed that all sources must be connected, in reality significant cost savings may be realised if it were acceptable to deem some remote out-lying CO2 sources as not economically viable.

“Near optimum” can be defined as a solution that is within 5-10% of the optimal (least) cost solution. It is felt that this degree of optimisation is suitable for the scope of this study, though this 5-10% sub-optimality is occasionally noticeable in the form of some small anomalies in the results. Better optimisation is possible from the algorithm given a longer project duration and scope, but none of the input data and none of the economic models is of better accuracy and so striving for better results from the optimisation algorithm alone would be misleading.

6.4.2 Process Overview

Using the six CO2 source datasets from WP3 it was initially assumed that the model should allow any of the sinks to be used, assuming the minimum capacity threshold discussed in section 6.3, but the chosen solution would not require that all sinks be used.

A structured three-stage process was adopted:

- Automatically build a pipeline network that connects all sinks and sources in the data set being analysed
- Create a fully functioning hydraulic model
- Systematically improve ('Optimise') the pipeline network to explore best-cost solutions

6.4.3 Network Creation & Optimisation

The initial network was created using one technique within the field of Graph Theory. This initial network is over-specified and then is reduced by the optimiser. Two schematics are shown below that show the initial over-specified network and the optimised network. It should be noted that the precise organisation of the initial network is not crucial in the process provided it connects all sinks and sources.

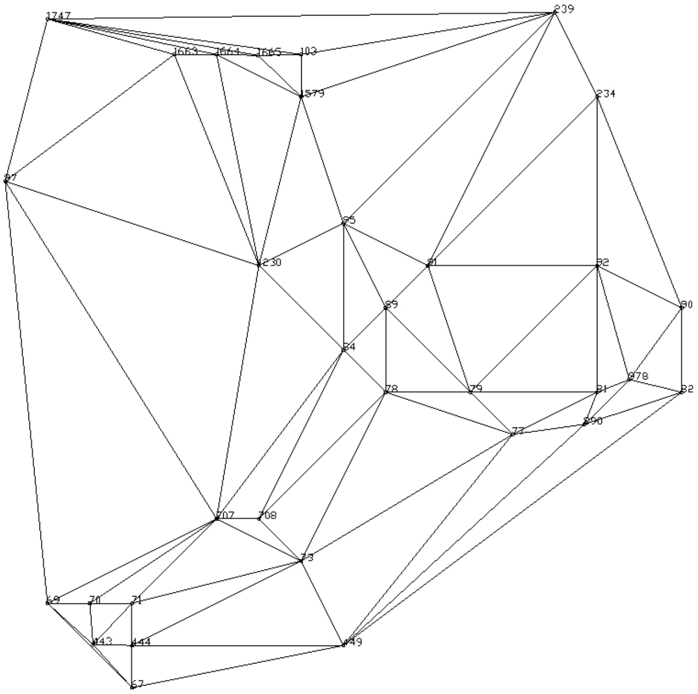


Figure 14 Over-specified Network

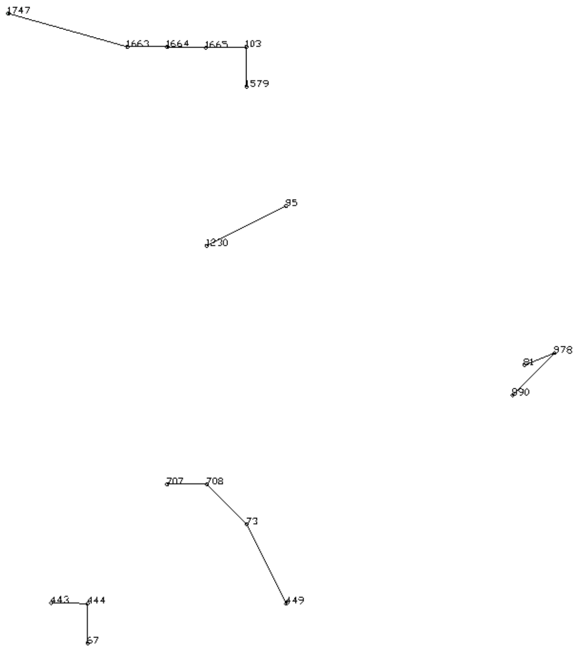


Figure 15 Improved (Optimised) Network

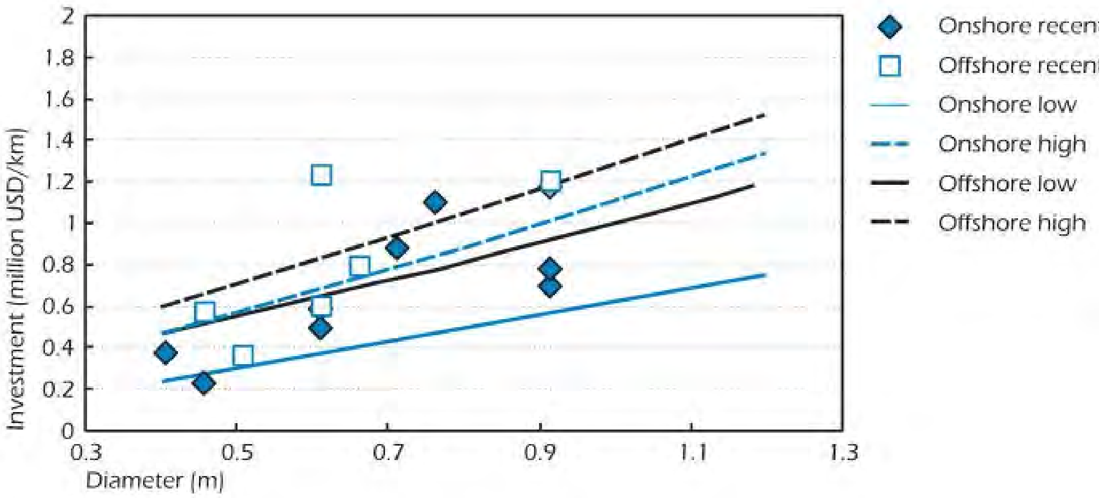
The optimisation process reduces the number and length of pipes so that the total cost is minimised and also ensure that all sources are connected but only those sinks that are needed are used.

6.4.4 Costing Approach

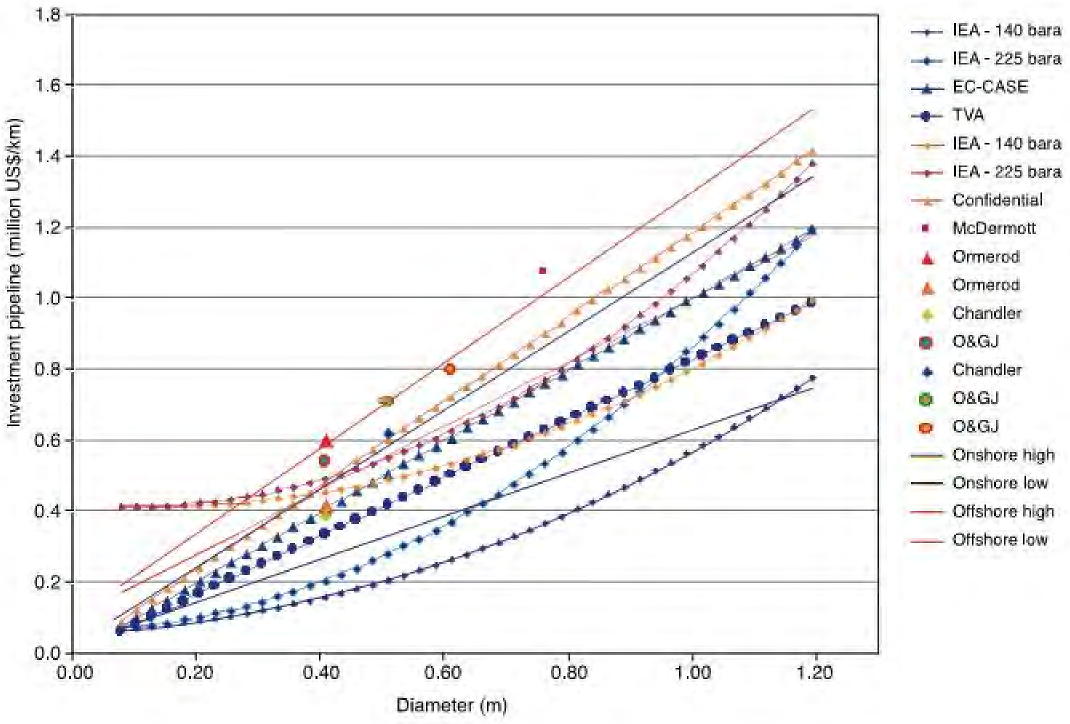
A typical pipeline cost equation has been derived from two technical reports that have been used previously in the study of CCS networks:

- "IEA Energy Technology Analysis CO2 Capture and Storage, A key carbon abatement option", which in turn refers to…
- "IPCC Special Report on Carbon Dioxide Capture and Storage"

IEA:



IPCC 2005:



Based on these cost curves and reference sources the following cost model has been used:

- Pipeline costs = €37,500/km/inch of diameter

- Booster station cost €4.5million per MW

Economies of scale in pipeline construction are embodied in this cost model; twice the flow is gained for approximately 30% extra construction cost assuming like-for-like pressure gradients. The impact of these economies of scale on the optimisation algorithm in the hydraulic model is to preferentially select a small number of large diameter trunk mains as opposed to a large number of small diameter pipelines.

The objective of this study is to focus on network costs and so costs related to development of the sinks and sources have not been included.

It is also worth noting that cost premiums associated with adverse terrain, subsea and cross-border costs have been omitted at this stage.

Operating costs have also been omitted at this stage. At this level of assessment operating costs are considered so small that they lie within the bounds of accuracy of the capital cost estimates.

The above costing equation does not impose any limit to the pipe sizes, but our analysis shows that some large diameter pipes will be needed. For notional pipe diameters larger than those typically constructed it is assumed that pipes can be twinned to provide the same capacity at a similar cost.

6.4.5 Design Basis

Previous CCS projects have shown that the major trunk mains (rather than any localised gathering and distribution systems) are likely to operate in the dense phase region and this has been assumed in the modelling.

Traditionally pipeline design begins with using a design velocity that is developed from past experience. This design velocity differs between industries and for different liquids and gasses. This design velocity helps to prevent excessive pressures losses, erosion and wear and tends to keep surge pressures within reasonable limits. Once a design progresses from concept to detailed design the actual flowing velocity is often allowed to vary slightly from the standard design velocity. The CO2 transport industry is not yet mature enough to have robust design velocities, so typical operating pressures and assumed standard Oil & Gas industry pipe standards were explored to ensure that the surge pressures stay below the short term overpressure limits. As a result a 2m/s design velocity was initially deemed suitable.

Following a review of several of the operating CO2 pipelines it was apparent that a slightly higher velocity is being used which, if adopted in the model, would reduce the overall costs. The average of three operating pipelines was used in the final model with a design velocity of 2.77m/s.

The pipe cost equations available for use in this study do not account for system design pressure, so it is not productive to concentrate unduly upon design pressure. The underlying hydraulic models are capable of including design pressure once more detailed work is needed.

At this early stage in engineering design, the precise location of the necessary booster stations is unknown. The location, size and quantity of these can only be calculated once the network design, geometry and diameter is finalised. A typical range of diameters was used to determine a likely spacing for the booster stations and the costs for each station were then apportioned using pipeline length and diameter. As the cost of booster stations is low in comparison to the pipeline costs (and probably the sink and source costs) this approach is believed to be suitable for the current work.

The density of CO2 changes with temperature and pressure and so will vary around the pipeline network. But the density also varies with the amount and type of impurities and this variation alone can be significant. Once the design progresses, iy would be possible to use sophisticated physical property predictors that will calculate the density, but for a high level study such as this one the operating pressures and impurities are not yet defined. So the density published by the UK DTI[3] has been assumed for this study (700 kg/m^3).

Standard pipeline economic design uses a range of design life values of between 20 and 25 years, and similar ranges have been discussed in other research work on CO2 pipelines. The design life is that point where it is assumed that major rehabilitation, repair and replacement is needed to continue to operate the system. The costs of operating beyond the design life are not incorporated in the standard costing algorithms and so cannot be incorporated into our study.

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[3] DTI – Oil & Gas - Maximising Recovery Programme website

One consequence of using a design life in the economic model is seen in the utilisation of the sink capacity. Conceptually, the sink capacity could be used with a high flow so that the volume is filled quickly or a lower flow could be used that extends the design life. We reasoned that even if injectivity rates were unrestricted, it would be inefficient to use high flows that reduce the design life of sinks when the standard cost equations for pipeline assume a long design life. So we assumed the same design life for sinks and ensured that high flows do not occur that reduces that design life (and hence prematurely fills the available sink capacity). Although no work has been undertaken within this scope of work to quantify this aspect, we suspect that a better understanding of the design life and the impact upon the pipelines source and sink costs models would be beneficial.

6.4.6 Summary

Several assumptions are have been made in setting up the network model. It is likely that some of these may have an appreciable impact upon the costs of the pipeline network. Additional sensitivity work should be undertaken to quantify the impact upon the network and the total costs.

6.5 Gathering Systems & Clustering

6.5.1 Introduction

As discussed earlier there are differences in pipeline network strategy between predominantly ‘A to B’ pipelines and the gathering systems used frequently in the Oil & Gas industries. It is unusual in the pipeline industry to have such a large system to design and optimise, so we reviewed the experience of the telecommunications and data networking industries.

6.5.2 Clustering

Gathering systems work in a similar way as telephone networks, where a series of smaller feeds connect sources (the equivalent of houses in telecommunications) to local hubs. There is a huge and well proven body or work that enables entire data sets to be studied to establish if there are any logical ways to split up the whole problem or geographic region in smaller areas that would benefit from being designed as a gathering system.

This clustering theory can become complex (see for example Sani and Gonzalez[4] or Gorke, Hartmann and Wagner[5]) but little of that is needed in the CO2 project because the data naturally falls into several large clusters, as shown below.

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[4] P-Complete Approximate Problems, Sahni and Gonzalez

[5] Dynamic Clustering using Minimum Cut Trees, Gorke, Hartmann and Wagner

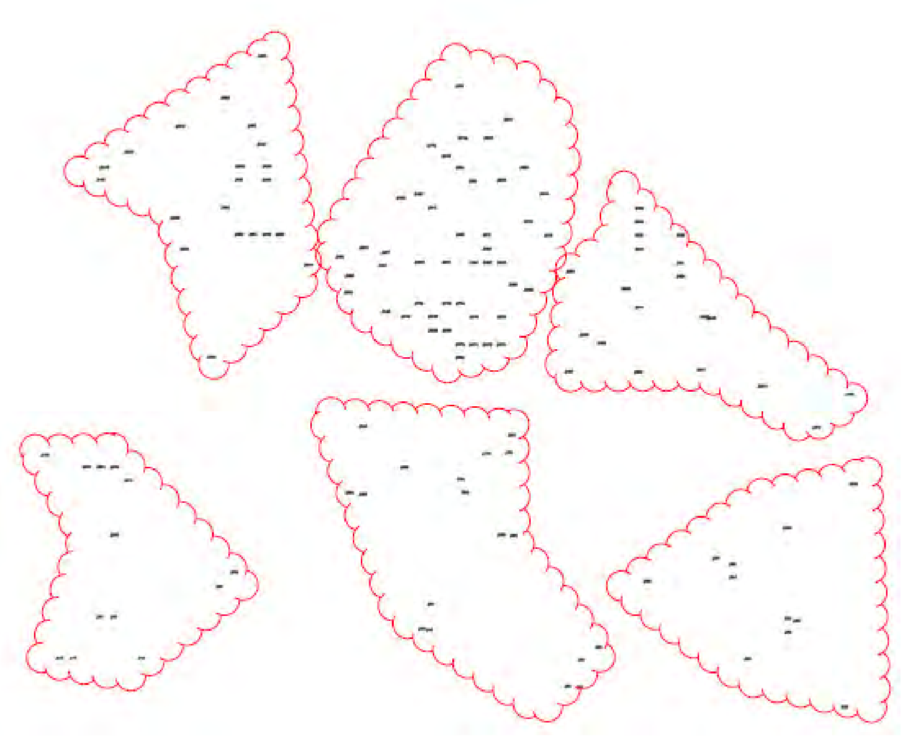


Figure 16 Clusters of CO2 Sources

The clusters have been numbered 1-6 based upon the capacity and the countries involved and are listed in the table below:

Cluster	**Principal Countries**
1 - North East	Poland, Hungary, Czech Republic, Slovakia, Austria
2 - North	Germany, Poland, Belgium, Czech Republic, France, Denmark
3 - North West	UK, Ireland
4 - South West	Spain
5 - South	Italy
6 - South East	Greece, Croatia, Bulgaria, FYROM, Bosnia and Herzegovina, Romania, Albania

Table 2 Clusters

It was agreed at an intermediate stage in the project that these clusters would be used as a basis for developing the European CO2 infrastructure network. This means that the pipeline network will resemble a gathering system, with several major clusters of sources/sinks interconnected where necessary by major trunk mains.

6.5.3 Source & Sink Clusters

At an early stage in the project, separate clustering of source and sink data was investigated. This which would lead to a pipeline network that has gathering and distribution networks with trunk mains connecting both. The review concluded that the overall sparseness of the data and the abundance of sink capacity would mean that it is preferable and lower cost to use only the source data clusters as a basis for the network. The results discussed below seem to support this, but additional work could be undertaken if needed.

6.5.4 Exceptions & Manual Decisions

The clustering algorithms formed an excellent basis for the next stage in the process, but the following ‘manual’ decisions were made:

- The France sources were added to Cluster No 2 to avoid subsea pipelines
- The Sinks in the North Sea are not needed by mainland Europe so are included (because they are needed) in the UK and Ireland cluster
- The abundance of sinks in Germany and Poland was simplified slightly by assuming small distribution system connecting some sinks.

Although North Sea sinks were ‘associated’ with the UK & Ireland cluster, they were equally available to all source clusters if the model deemed that to be the most cost-effective route.

6.5.5 Summary

Theory drawn from the data networking and telecommunication industries has allowed a European network to be structured into six high-level clusters of sources and sinks. High-level super trunk mains will then be created as needed to interconnect these high level clusters of CO2 sources or sink capacity. So for example, if any cluster has an inadequate sink capacity then the network will be extended to include trunk mains to export the excess CO2 to adjacent clusters that have spare capacity. There is an underpinning assumption that all storage sites are available without any restrictions; political, public acceptance, etc.

6.6 Results

6.6.1 Introduction

The hydraulic modelling process outlined in section 6.4.3 produces a list of pipelines with the following data:

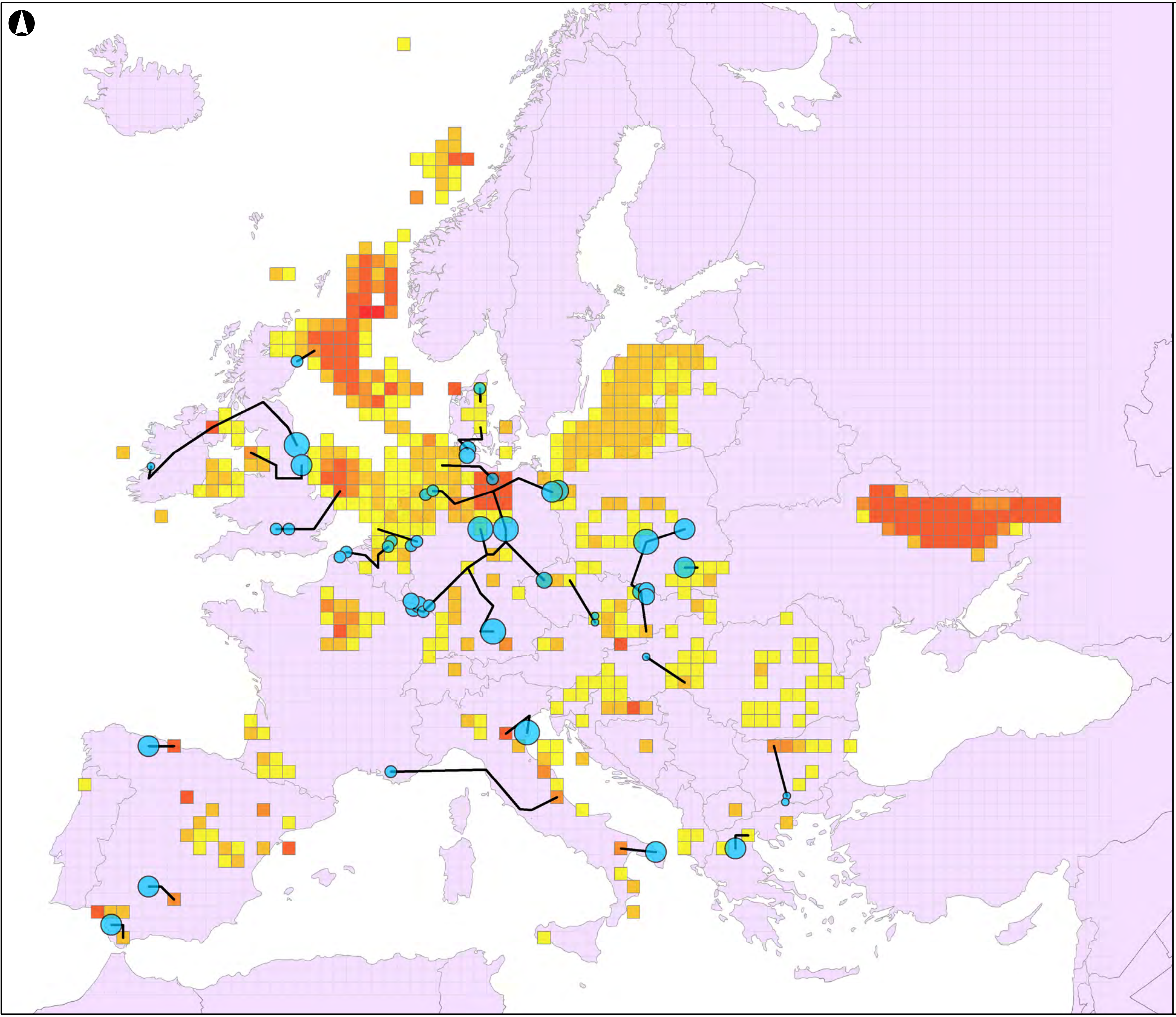
- Diameter
- Start point, End point and Length
- Flow
- Cost

This data has been exported from the hydraulic model in a form that can be processed in ArcGIS to produce a geographical presentation of the resulting network.

The following sections summarise the network modelling outputs for each of the six scenarios in the form of a network map, and also tabulated data describing the length of each pipe diameter. The study has assumed standard diameters from BS1600 up to 36 inch and then API for larger diameters. Not all of the pipe diameters in the standards are in common use, but using the full suite of 'standard' diameters is appropriate for this study. Selection of the closest preferred pipe diameter would be made during the design of future projects.

Two scenarios for the various source profiles have been examined:

- The first six network maps illustrate CO2 infrastructure required if all storage is available with no restriction; political, public acceptability, etc.
- The subsequent six network maps illustrate CO2 infrastructure required if only offshore storage is deemed to be available/acceptable.



Legend

CO2 captured in MT/yr 2030 L

- ● 0.27 - 0.5
- ● 0.5 - 1
- ● 1 - 1.4
- ● 1.4 - 1.7
- ● 1.7 - 2

Pipelines 2030 L

—

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ▨ Country Boundaries

P1	24-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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TREN/372-1/C3/2009

Drawing Title

CO2 Transportation Infrastructure
2030-Lo CO2 Capture Scenario

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
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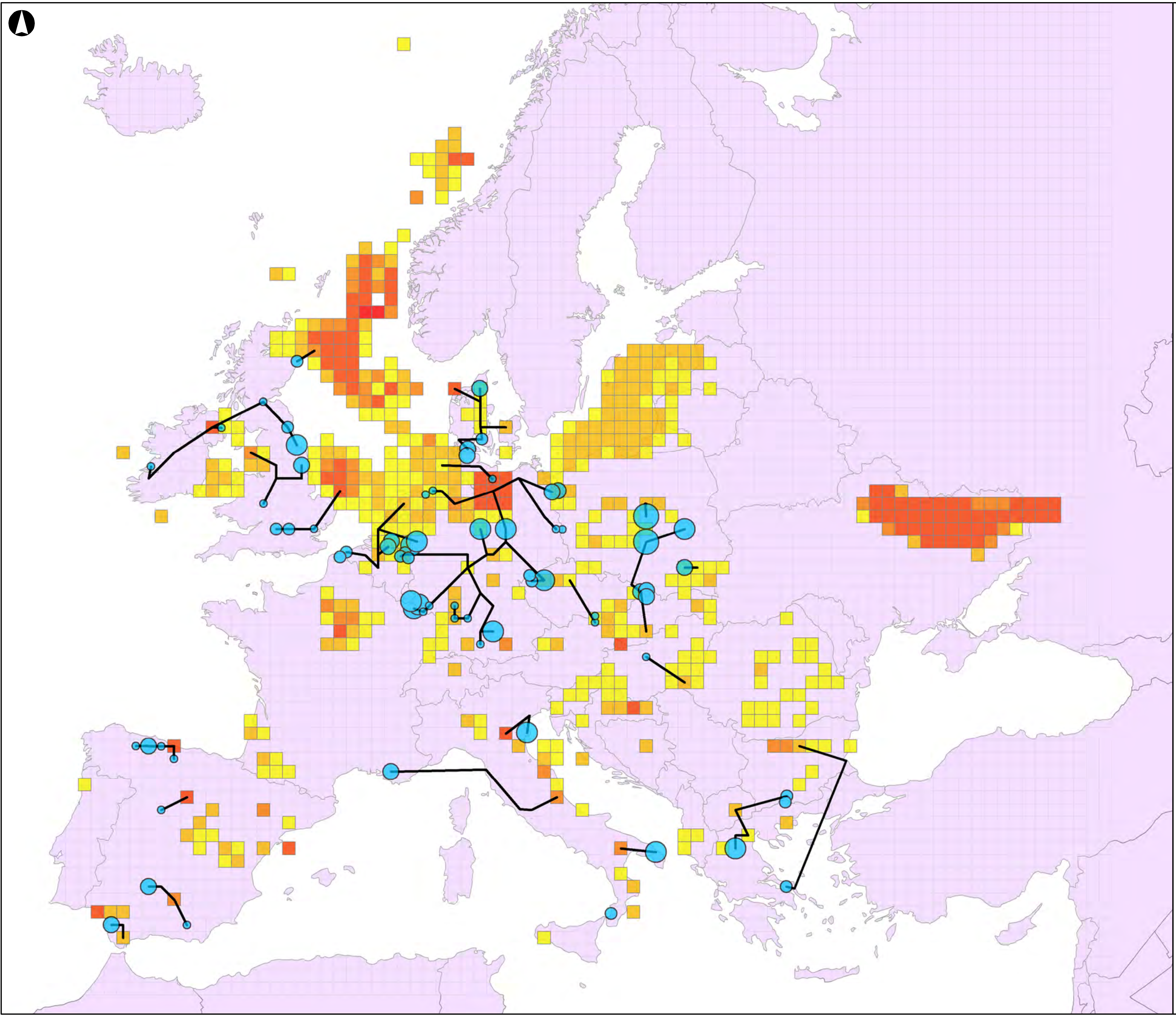
A3



Legend

CO2 captured in MT/yr 2030 M

- ● 0.65 - 1
- ● 1 - 1.5
- ● 1.5 - 2.5
- ● 2.5- 4.6
- ● 4.6 - 7

Pipelines 2030 M

—

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ▨ Country Boundaries

P1	24-09-10	RC	DA	DA
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Metres
0 195,000 390,000 780,000

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Drawing Title
CO2 Transportation Infrastructure
2030-Mid CO2 Capture Scenario

Scale at A3
1:14,000,000

Drawing Status
For Information

Job No	Drawing No	Issue
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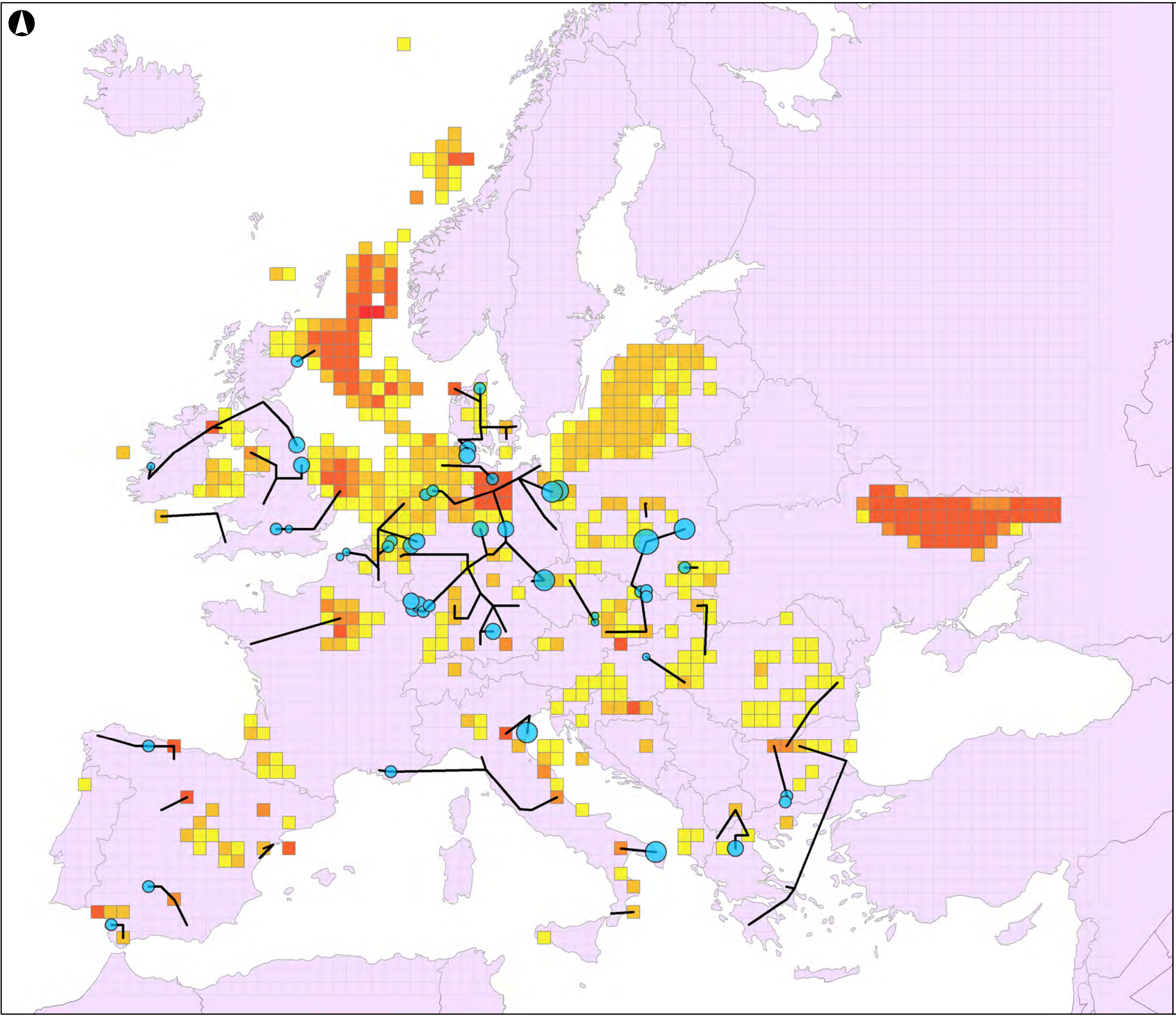
Template A3: Version 2

A3



Legend

CO2 captured in MT/yr 2030 H

- ● 1 - 2
- ● 2 - 5
- ● 5 - 7.5
- ● 7.5 - 12
- ● 12 - 19.4

Pipelines 2030 H

—

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ☐ Country Boundaries

P1	24-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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CO2 Transportation Infrastructure
2030-Hi CO2 Capture Scenario

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
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Template A3: Version 2

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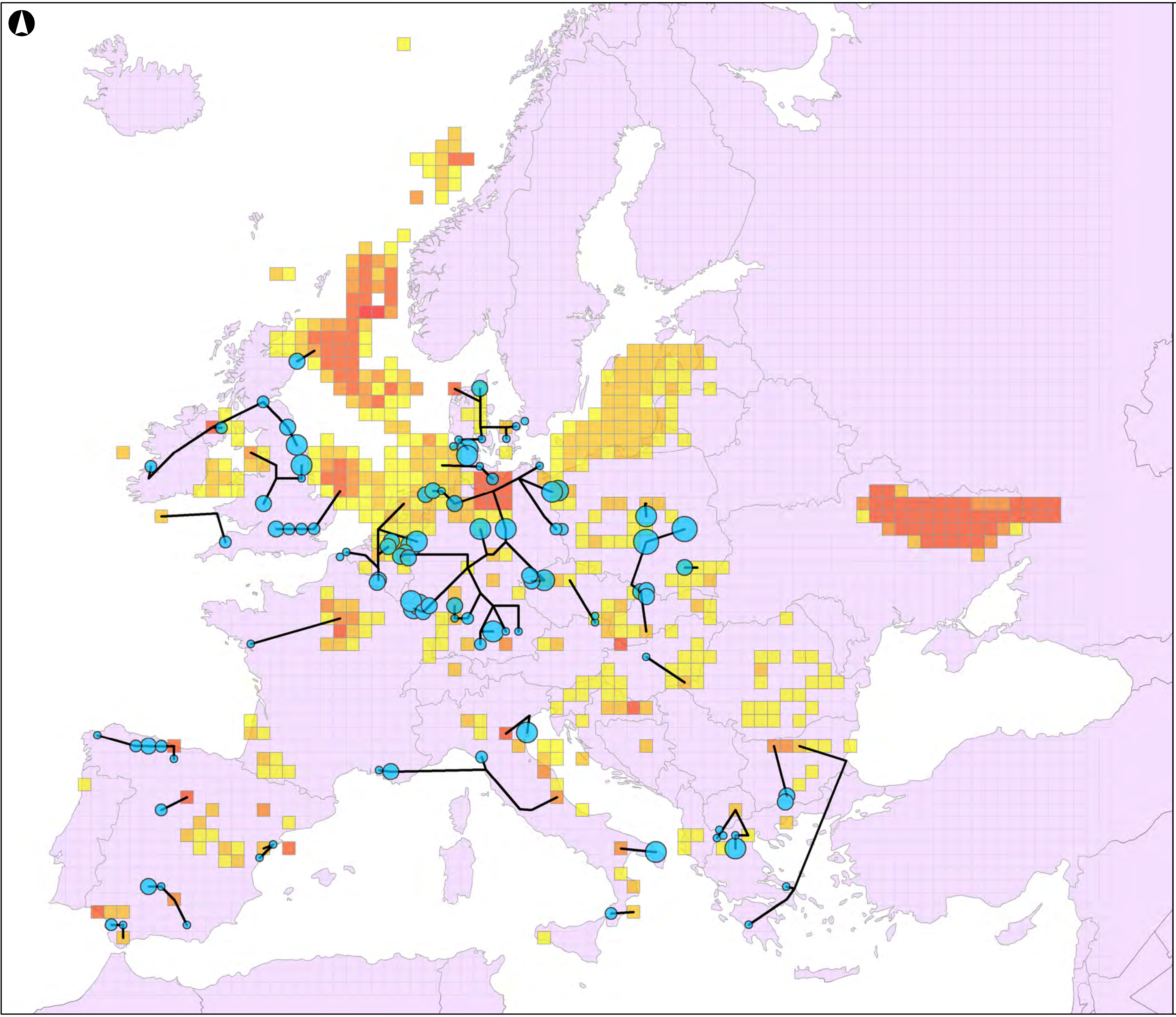

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Metres
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CO2 Transportation Infrastructure
2050-Lo CO2 Capture Scenario

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
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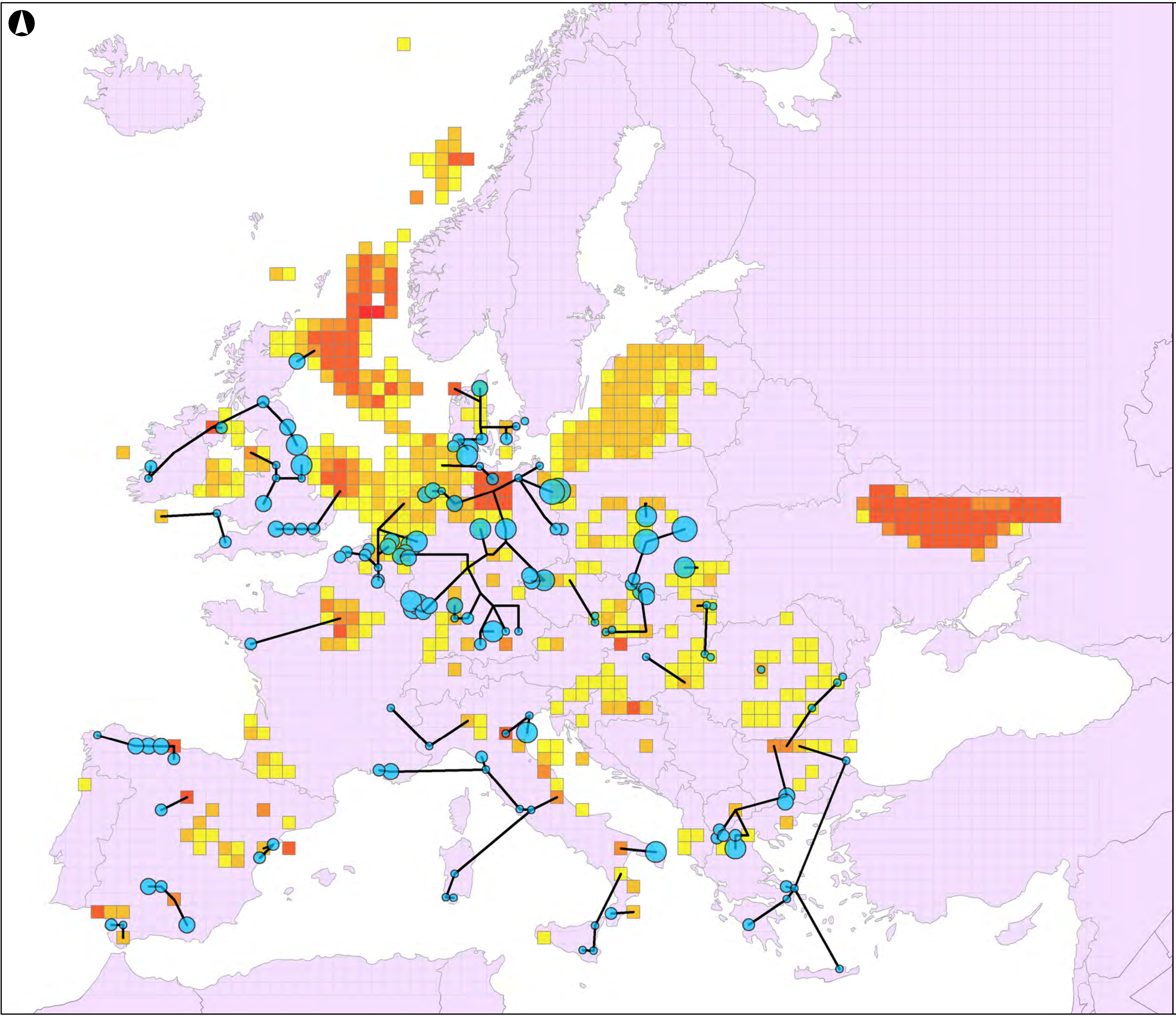
A3



Legend

CO2 captured in MT/yr 2050 M

- ● 1 - 2.4
- ● 2.4 - 4
- ● 4 - 8
- ● 8 - 14
- ● 14 - 28

Pipelines 2050 M

—

CO2 Storage in MT

- 🟨 0 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000
- ☐ Europe Grid
- ▨ Country Boundaries

P1	24-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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Drawing Title

CO2 Transportation Infrastructure
2050-Mid CO2 Capture Scenario

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
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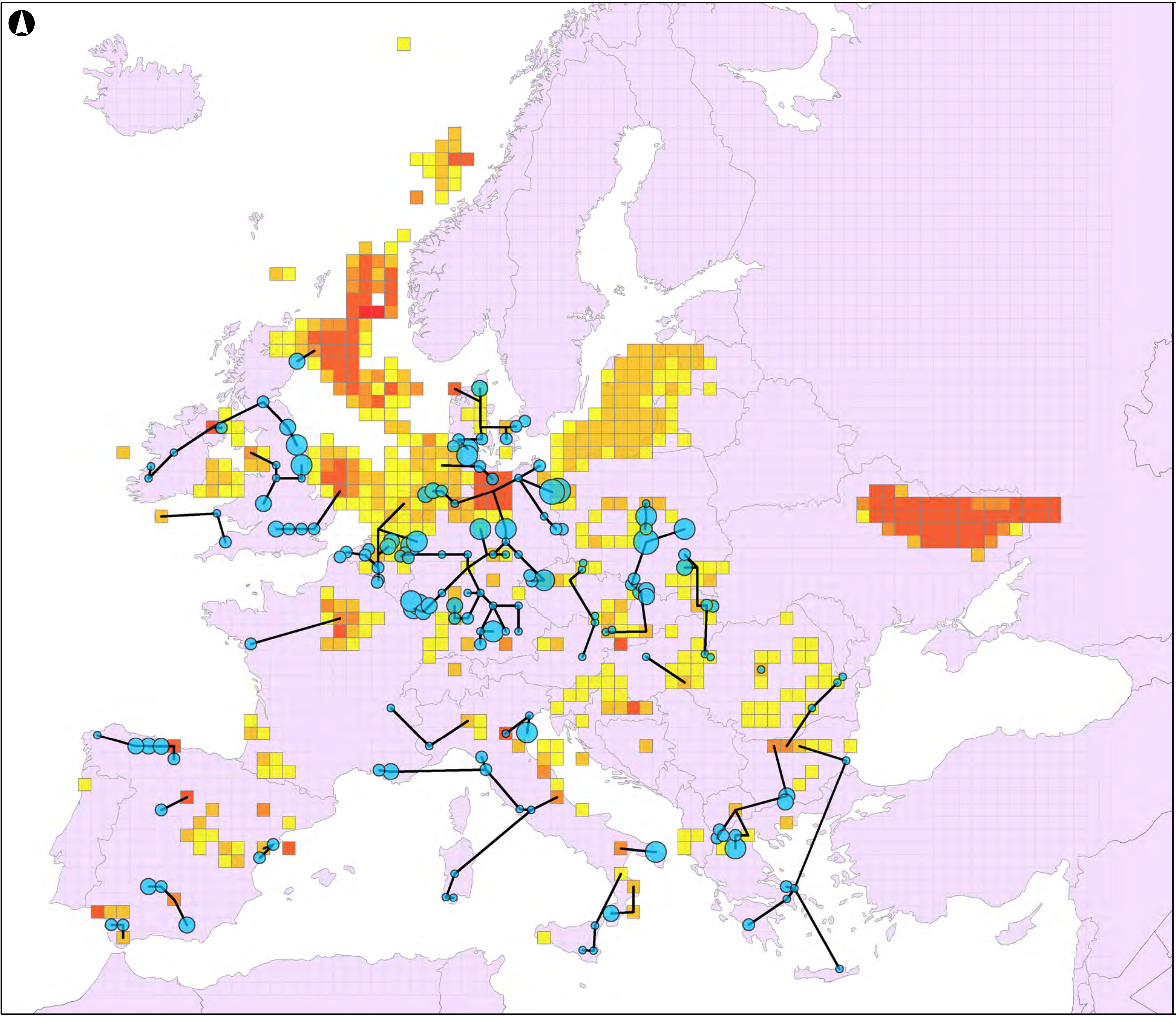
Template A3: Version 2



Legend

CO2 captured in MT/yr 2050 H

- ● 1 - 2.8
- ● 2.8 - 6
- ● 6 - 11
- ● 11 - 18
- ● 18 - 28

Pipelines 2050 H

—

CO2 Storage in MT

🟨	0 - 100
🟨	100 - 500
🟧	500 - 1000
🟧	1000 - 5000
🟥	5000 - 10000
☐	Europe Grid
▨	Country Boundaries

P1	24-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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Scale at A3

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Drawing Status

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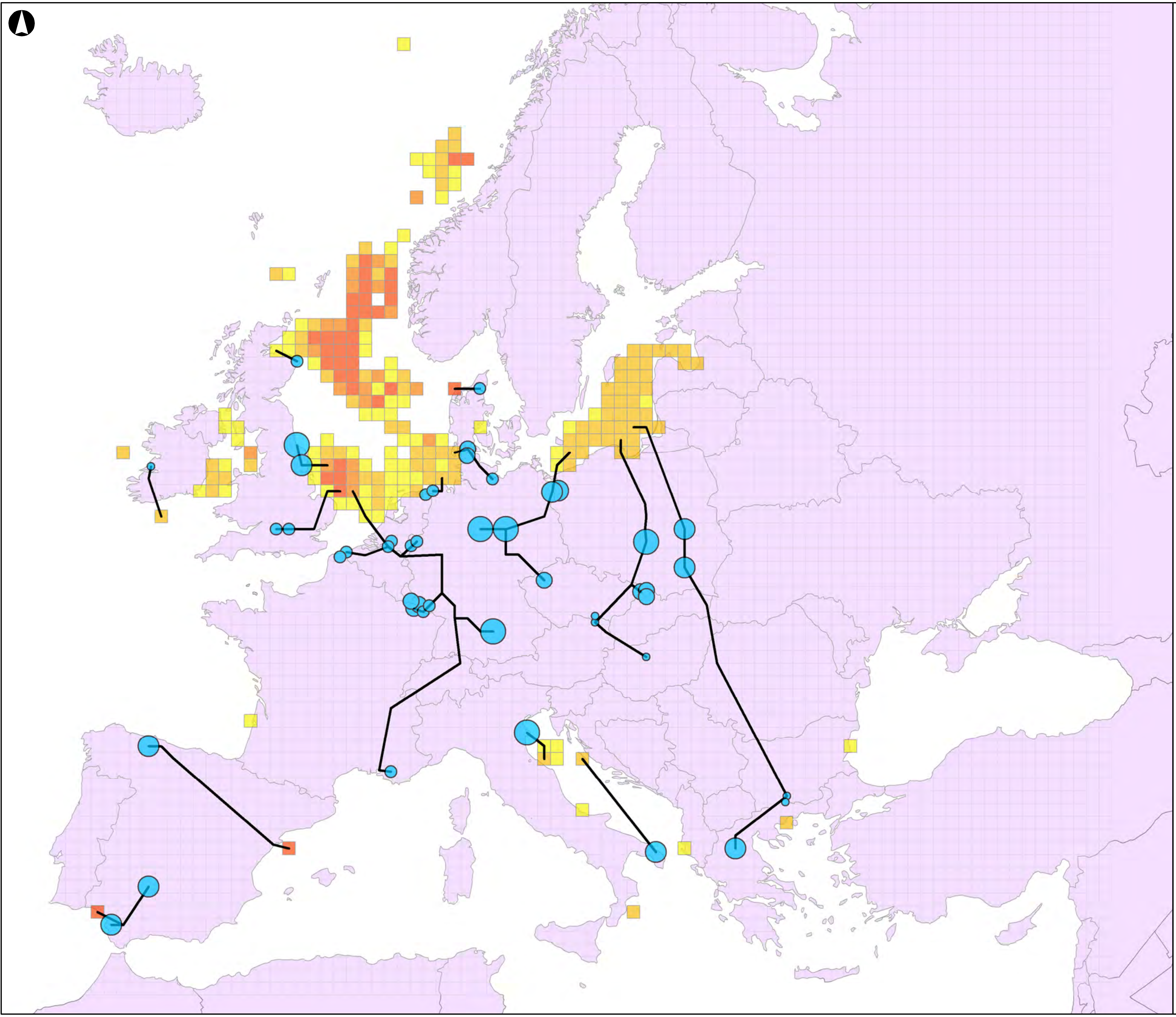

Legend

— Pipelines - 2030 Lo - Offshore

CO2 captured in MT/yr 2030 L

● 0.27 - 0.5
● 0.5 - 1
● 1 - 1.4
● 1.4 - 1.7
● 1.7 - 2

CO2 Storage (Mt) - Offshore

🟨 0.40 - 100
🟨 100 - 500
🟧 500 - 1000
🟧 1000 - 10000
🟥 10000 - 10200
☐ Europe Grid
☐ Country Boundaries

P1	08-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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Drawing Title

CO2 Transportation Infrastructure
2030-Lo CO2 Capture Scenario
Offshore Storage Only

Scale at A3

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Drawing Status

For Information

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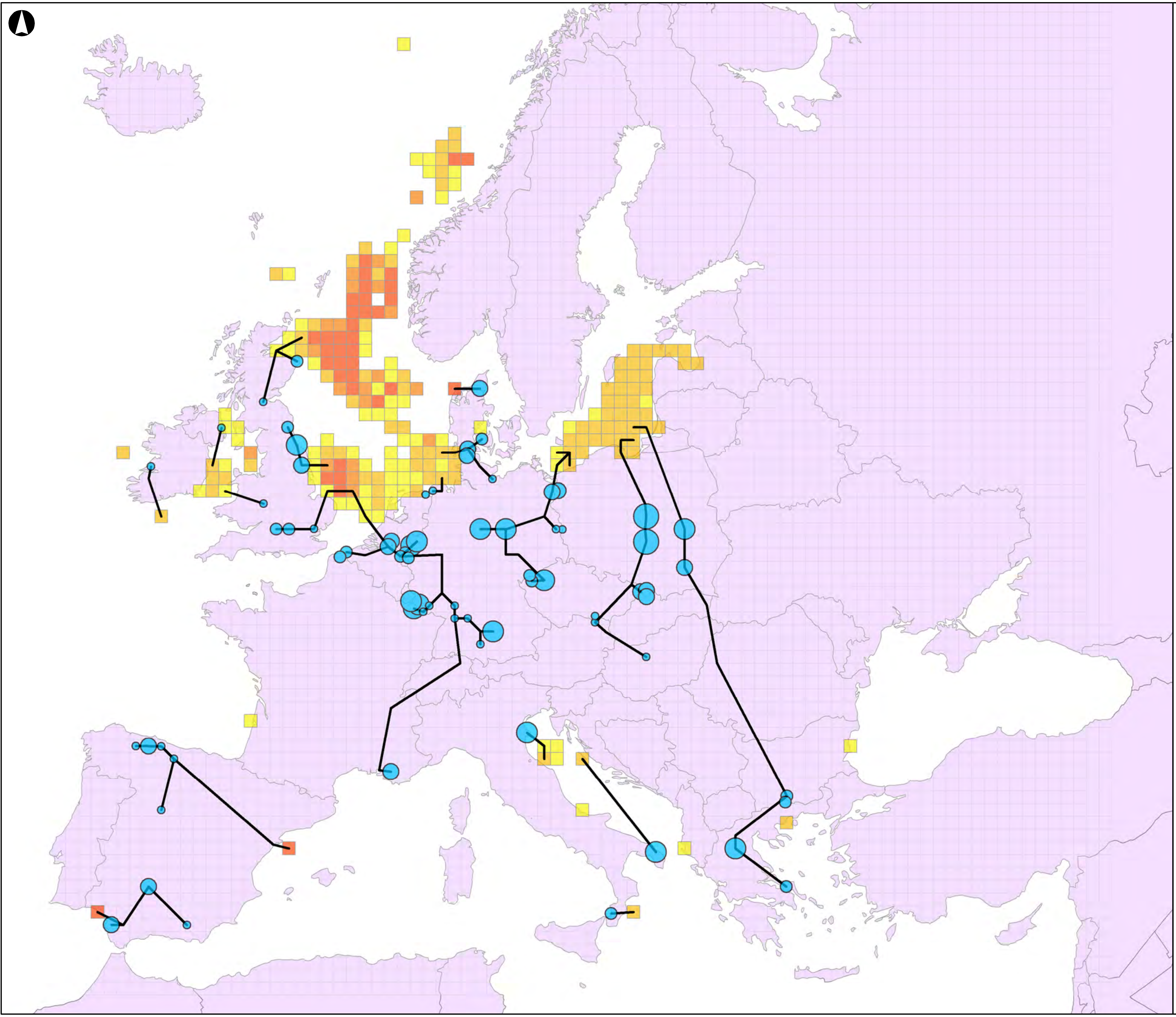
A3



Legend

— Pipelines - 2030 Mid - Offshore

CO2 captured in MT/yr 2030 M

- ● 0.65 - 1
- ● 1 - 1.5
- ● 1.5 - 2.5
- ● 2.5- 4.6
- ● 4.6 - 7

CO2 Storage (Mt) - Offshore

- 🟨 0.40 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 10000
- 🟥 10000 - 10200
- ☐ Europe Grid
- ☐ Country Boundaries

P1	08-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres
0 195,000 390,000 780,000

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CO2 Transportation Infrastructure
2030-Mid CO2 Capture Scenario
Offshore Storage Only

Scale at A3

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Drawing Status

For Information

Job No	Drawing No	Issue
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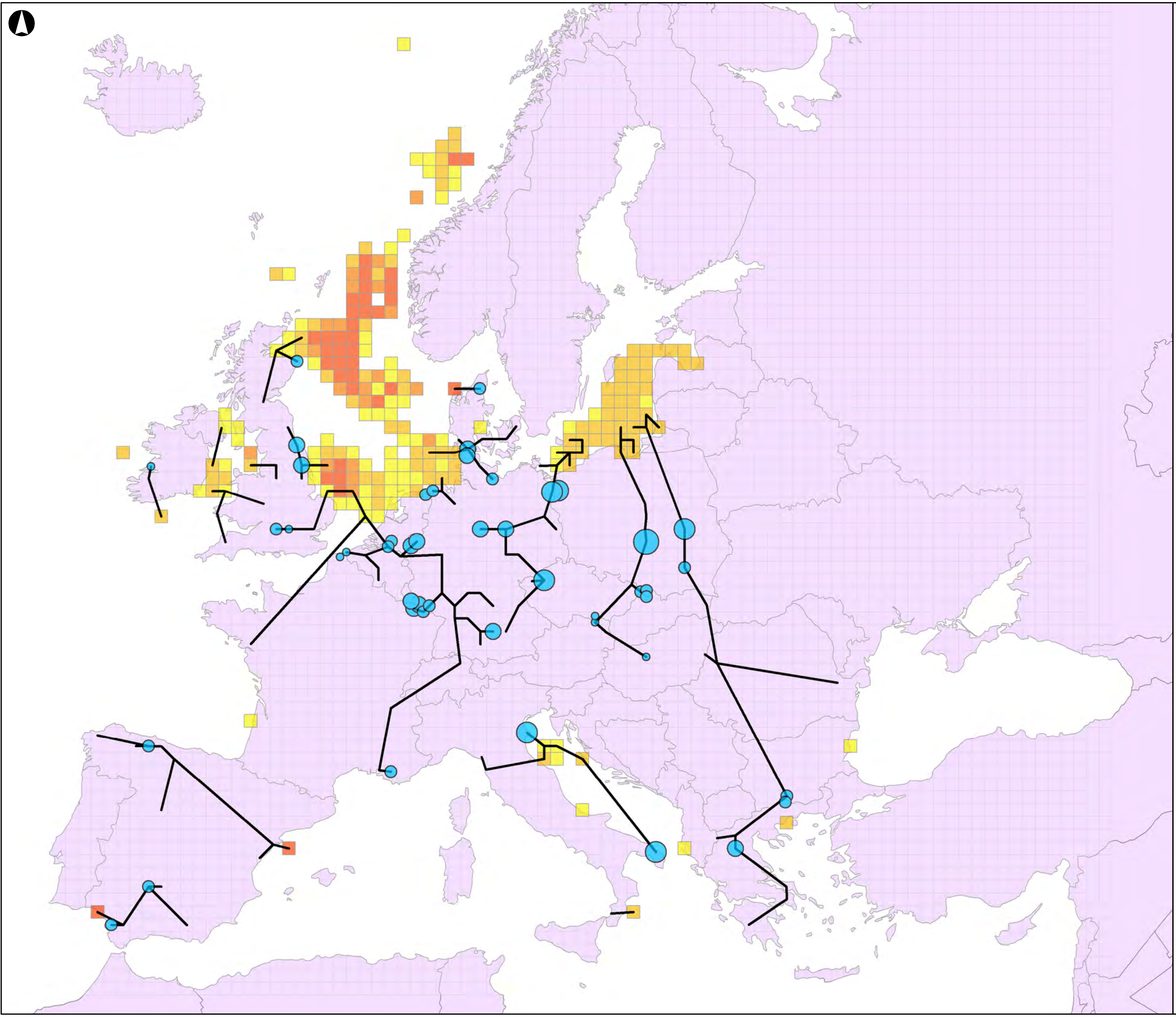
Template A3: Version 2



Legend

▬ Pipelines - 2030 Hi - Offshore

CO2 captured in MT/yr 2030 H

- ● 1 - 2
- ● 2 - 5
- ● 5 - 7.5
- ● 7.5 - 12
- ● 12 - 19.4

CO2 Storage (Mt) - Offshore

- 🟨 0.40 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 10000
- 🟥 10000 - 10200
- ☐ Europe Grid
- ☐ Country Boundaries

P1	08-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres

0 195,000 390,000 780,000

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2030-Hi CO2 Capture Scenario
Offshore Storage Only

Scale at A3

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Drawing Status

For Information

Job No	Drawing No	Issue
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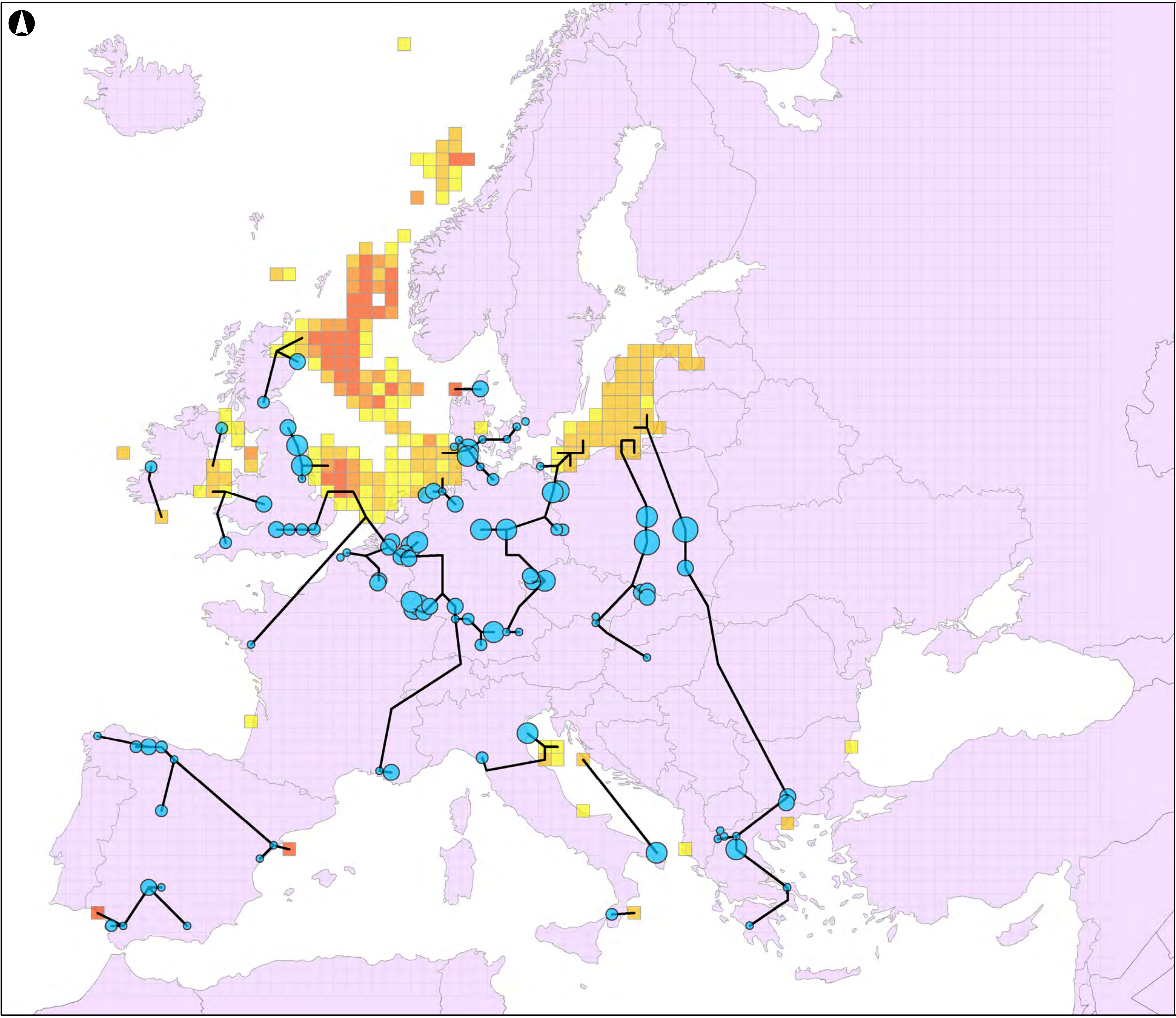
A3



Legend

━ Pipelines - 2050 Lo - Offshore

CO2 captured in MT/yr 2050 L

● 1- 1.6
● 1.6 - 2.3
● 2.3 - 4
● 4 - 8
● 8 - 15

CO2 Storage (Mt) - Offshore

🟨 0.40 - 100
🟨 100 - 500
🟧 500 - 1000
🟧 1000 - 10000
🟥 10000 - 10200
☐ Europe Grid
☐ Country Boundaries

Issue	Date	By	Chkd	Appd
P1	08-09-10	RC	DA	DA

Metres
0 195,000 390,000 780,000

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Drawing Title

CO2 Transportation Infrastructure
2050-Lo CO2 Capture Scenario
Offshore Storage Only

Scale at A3
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Drawing Status
For Information

Job No	Drawing No	Issue
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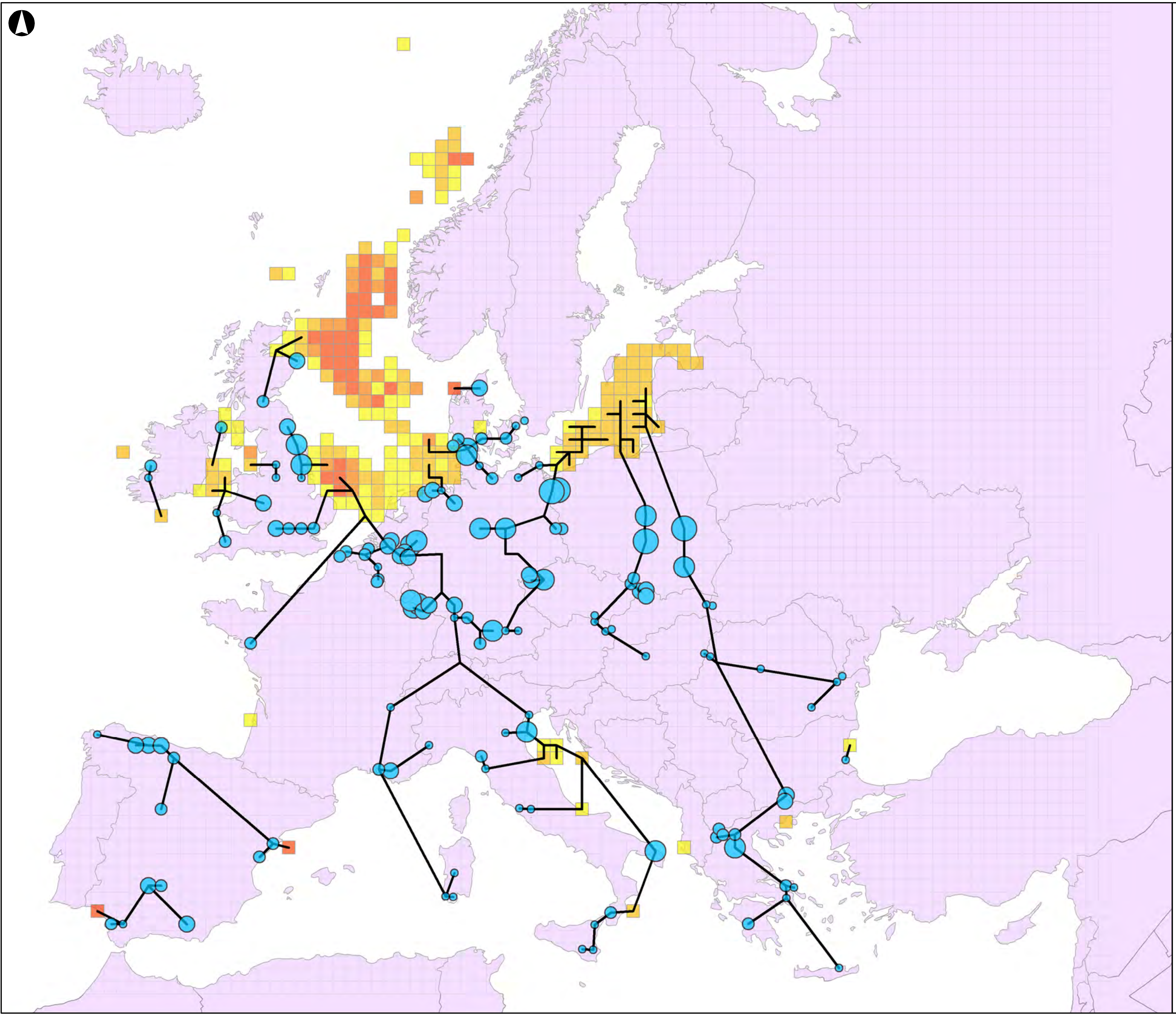
A3



Legend

— Pipelines - 2050 Mid - Offshore

CO2 captured in MT/yr 2050 M

- ● 1 - 2.4
- ● 2.4 - 4
- ● 4 - 8
- ● 8 - 14
- ● 14 - 28

CO2 Storage (Mt) - Offshore

- 🟨 0.40 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 10000
- 🟥 10000 - 10200
- ☐ Europe Grid
- ☐ Country Boundaries

P1	08-09-10	RC	DA	DA
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2050-Mid CO2 Capture Scenario
Offshore Storage Only**

Scale at A3

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Drawing Status

For Information

Job No	Drawing No	Issue
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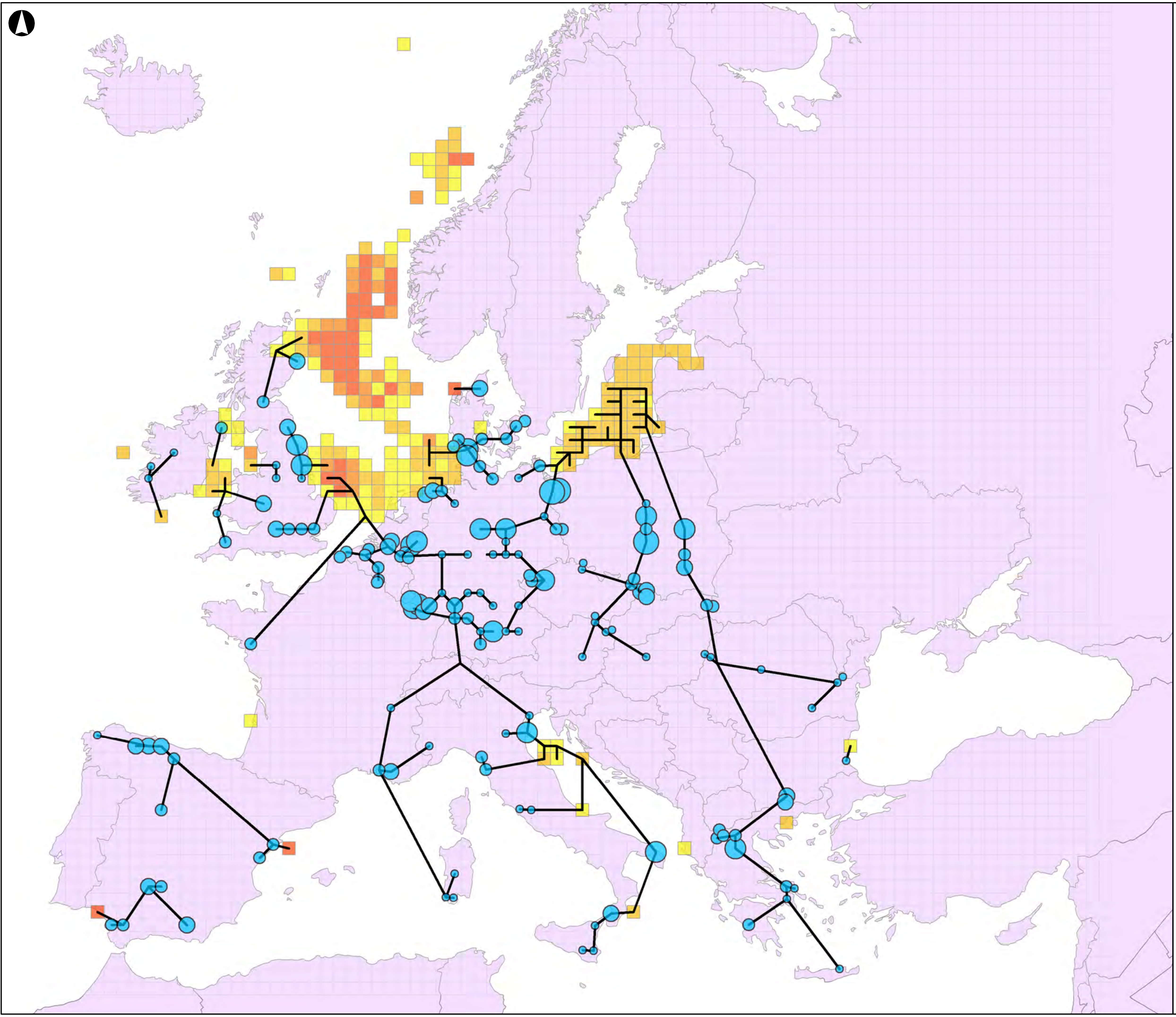

Legend

▬ Pipelines - 2050 Hi - Offshore

CO2 captured in MT/yr 2050 H

- ● 1 - 2.8
- ● 2.8 - 6
- ● 6 - 11
- ● 11 - 18
- ● 18 - 28

CO2 Storage (Mt) - Offshore

- 🟨 0.40 - 100
- 🟨 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 10000
- 🟥 10000 - 10200
- ☐ Europe Grid
- ▨ Country Boundaries

P1	08-09-10	RC	DA	DA
Issue	Date	By	Chkd	Appd

Metres

0 195,000 390,000 780,000

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2050-Hi CO2 Capture Scenario
Offshore Storage Only**

Scale at A3

1:14,000,000

Drawing Status

For Information

Job No	Drawing No	Issue
212043-00	**OAP-CO2-T2-2050-H**	**P1**

6.6.2 Summary of CO2 Network Lengths and Costs

The table below shows the total capital cost of pipeline infrastructure for each scenario.

All storage available:

Scenario	Total Length (km)	Total Cost (€m)	Cost per Tonne CO2 (€)
2030 Low	6879	2074	0.58
2030 Medium	9719	4011	0.65
2030 High	12384	7592	0.89
2050 Low	11775	6785	0.78
2050 Medium	14334	10901	1.16
2050 High	15013	12667	1.45

Offshore storage only:

Scenario	Total Length (km)	Total Cost (€m)	Cost per Tonne CO2 (€)
2030 Low	8971	3434	0.90
2030 Medium	10829	5747	0.98
2030 High	14908	11206	1.25
2050 Low	13746	9560	1.15
2050 Medium	18635	16439	1.66
2050 High	20041	19781	2.40

Table 3 Costs

The economy of scale gained from using larger diameter pipes delivering higher flows can clearly be seen from the costs per tonne of CO2 transported. In addition, the lower flow scenarios show some sources as not flowing and so fewer pipes are needed which make a significant difference to the system.

The alternative, offshore only, storage scenario results in an increase in total pipe length of between 11% and 33%, and an increase in total cost of between 40% and 65% compared with the scenario where all storage is available.

6.7 Conclusions

6.7.1 Pipeline networks – all storage available

The abundance of onshore sink capacity means that the European CO2 pipeline infrastructure should comprise 23 long but ‘simple’ pipeline systems, each which can be built and operated independently. Two slightly more complex networks are needed and one notably integrated network is required in central Europe.

The cost of this network will be between €7592 and €12667 million by 2050, but may be as low as €2074 million in 2030. The dominance of simple pipeline systems suggests that the planning and funding can be more easily managed than if a single integrated network was needed. Table 12 summarises the total costs for the pipeline networks across at each design horizon and for each of the three capture scenarios.

It is essential to realise that the optimum solutions show that there is no need to build trunk mains between the data clusters introduced in section 6.5. In fact, the concept of manually defining clusters became somewhat redundant as it was found that the cost-optimisation routine in the hydraulic model self-selected data clusters.

The table above shows a noticeable cost difference between the High and Low 2050 scenarios of 186% (a 127% difference in length). But the variance is far more significant in the 2030 scenario where the difference between High and Low CO2 scenarios is 366% of cost and 180% in length. This wide variation at 2030 must be recognised as a planning risk especially in comparison to the more predictable 2050 scenario.

6.7.2 Pipeline networks – offshore storage only

The scenario where only offshore storage is accepted, compared with the assumption that all storage is equally available, gives entirely different results.

The network maps associated with this alternative data set show a much greater degree of cross-border transportation, with CO2 transported predominantly northwards to the offshore sinks of the North Sea and the Baltic Sea. This means that there are eight major, complex pipe networks and 11 simpler networks, costing between €3434 million and €19781 million.

The availability of onshore storage is therefore a critical judgement. The model could be used to test more subtle effects, e.g. switch onshore storage on or off to reflect varying attitudes in different states.

6.7.3 Future-proofing pipeline infrastructure

The objectives of this study do not include a detailed investigation of the best progression from 2030 to 2050, but the brief comparisons below do suggest that a more detailed economic analysis would be useful.

The source flow rate increase from 2030 to 2050 is summarised on Table 4 below:

	2030	2050	Increase
High	386.4	871.7	485.3
Medium	138.9	667.6	528.7
Low	57.2	307.7	250.5

Table 4 Source Capacity Increase (Mt/yr)

Progression Scenario	Comparison of Total Costs (€m)	No. of Coincidental Pipes with capacity for 2050 flows
2030 Low → 2050 Low	2074 → 6785	0 of 69
2030 Mid → 2050 Mid	4011 → 10901	4 of 97
2030 Hi → 2050 Hi	7592 → 12667	3 of 120

Table 5 2030-2050 Progression Comparisons

These figures go some way to illustrate the magnitude of difference between the 2030 CO2 infrastructure requirements and the 2050 CO2 infrastructure requirements. If the difference in flow rate, and therefore pipe diameter required, was small then it would be appropriate to consider oversizing the “2030” pipeline so that it was able to accommodate 2050 flows. But the figures above suggest that, at a Europe-wide scale, the low flow scenarios could be so low that it may be economically beneficial to build smaller pipe networks with only a short design life, to be twinned/upgraded/ replaced at a later date to suit higher flow rates.

There will exist, of course, local and regional geographical variations in the magnitude of the difference between 2030 flows and 2050 flows. It would be useful to explore this further.

6.7.4 Cost Per Tonne

It is interesting to review the networks using the overall cost of the network apportioned per tonne of CO2 transported across the whole design life. This is shown in the table below and distinct differences are revealed between different clusters.

	2030	2050
High	0.78	0.58
Medium	1.16	0.65
Low	1.45	0.89

Table 6 Summary of Cost/tonne (€)

The results show that the cost per tonne is initially far higher for the lower 2030 flow rates than for the higher CO2 capture scenario in 2050. The cost per tonne in the low capacity scenarios is between 135% and 178% the cost at high flow which clearly demonstrates the economy of scale in pipeline industry (higher flows through larger diameter pipes are more cost effective). This relatively high start-up cost may be an economic issue in which case further work should be undertaken to identify commercial breakpoints and to decide which parts of the network could be built at which CO2 market values.

Although no work has yet been undertaken, it is reasonable to assume that this analysis could be extended to rank each pipeline and pipeline network using this parameter. It is likely to show that some are more viable than others.

6.8 Recommendations

6.8.1 Growth Strategy

The design intent at the start of this project was to develop a network that could begin to be built in 2030, but would still be useful for the 2050 flow rates. But section 6.7.3 highlights the magnitude of the difference in flow rates between 2030 and 2050, making up-front oversizing of pipelines less likely.

Further analysis is required to determine the most cost-effective progression in network development from 2030 to 2050. Nearly all 2030 pipeline routes are coincidental with those at 2050, but the magnitude of flow increases between 2030 and 2050, and wider economic factors, suggest that early installation of networks to accommodate 2050 flows will be unattractive.

It might be useful to consider installing smaller diameter pipelines with a shorter design life and be replaced or upgraded as flow rates increase.

The cost/risk of increasing capacity at a later date could be mitigated by planning for double-width wayleaves at an early stage.

6.8.2 Economic Cost Model

The pipeline network optimiser shows that a distributed network is the lowest cost infrastructure design strategy. But it should be remembered that this is optimised based upon the economic models used for this study (see 6.4.4). It can be expected that improving the detail of that economic model would offer a better insight and might change some of the findings. Certainly the cost of each sink should be incorporated due to the high number of available sinks, but several other additions could be considered:

- Terrain pipeline costs
- Cost of developing an injection point at a storage site (and the sensitivity of that cost to flowrate)
- Cross-border costs
- Design life
- Large diameter Vs Twinned Pipe costs

6.8.3 Flexibility

One observation made during the study that has not been explored in detail is that there does seem to be a range of possible pipe networks that are within 10-15% of the optimum costs. This suggests that wide-scale planning to find and implement the optimal solution may not be essential and that there is a beneficial degree of flexibility in the process. In other words there is a relatively low cost premium associated with sub-optimal networks, with a wide range of pipe routes having similar costs. This would be useful to quantify and explore further.

6.8.4 Value of promoting onshore storage

The stark difference in CO2 infrastructure costs outlined in section 6.6.2 between an “All Storage Available” scenario and an “Offshore Storage Only” scenario shows that there would be a significant economic benefit to be gained if widespread public and political acceptance of onshore storage could be achieved. The value of promoting and gaining this acceptance could be up to €7000 million in the 2050 High CO2 source scenario.

6.8.5 Use model for sensitivity testing

The model developed during this study could be used to test the sensitivity of CO2 network extents and costs to different source and sink scenarios. Recommended examples include:

- Switching off onshore storage beneath the UK and Germany (and other states where public opposition is at its strongest)
- Switching off the offshore Baltic Sea storage area to determine the cost-benefit of further exploration in that area
- Switching on the Ukraine Donets basin to test the ‘attraction’ of this potential sink to CO2 sources in eastern Europe.

7 WP5 - Making the data available to all interested parties

7.1 Aims of WP5

The aim of WP5 was to make the data on CO2 sources and storage sites available to all interested parties.

From the outset, the intention of the project team was to develop a Geographical Information System to display graphically the outputs from WP1-WP4, and also to create a framework that could be used as a permanent asset – a repository of CO2 source and sink data maintained centrally and updated/populated with new data as it becomes available.

7.2 Geographic Information Systems (GIS)

'Where' things are is a key consideration for the majority of real world problems e.g. where is the nearest still functioning hospital after an earthquake?, or how far is my proposed wind farm development from the national electricity infrastructure? The projects associated with these problems therefore require supporting geographic data, potentially from many sources, and tools for their management.

Geographic (or often GeoSpatial) Information Systems (GIS) are a way of capturing, storing, analysing, visualising and disseminating data that can be referenced to real world locations. They include tools to generate new data (e.g. from mobile survey devices), digitise paper-based records (e.g. land cadastre maps), and tie together many other existing, often disparate and large geographic datasets (e.g. country-wide topographic datasets). As a result GIS can help to centrally manage and visualise 'one version of the truth', and in doing so, reduce the risk of poor decision making.

Whilst GIS can answer the '*where'* questions, key strength lines in being able to also answer the '*what'* questions. Indeed, because GIS provide a link between geographic and non-geographic data, they are essentially intelligent digital maps. Providing tools to query both types of data enables scenarios modelling and solution identification. The more detailed the database behind the map, the more questions that can potentially be answered.

Additionally, in recognition of the value of the non-geographic data involved, if GIS are treated as a fundamental component of an information management strategy considering all information types together with standards and quality, the value they can add is increased further.

In summary, GIS can be used to help bring together and manage 'one version of the truth' to help solve geographic problems, **reducing risk** and potentially **saving time and money.**.

7.3 Project GIS for Europe-wide CO2 Infrastructures Feasibility Study

GIS has been used as a tool to manage and interpret the large amount of data handled on this project, and forms one of the project deliverables. The aim is to implement a system which provides a means to manage and distribute geographical information

(GI) to all the project delivery partners as well as forming a useful repository for related documentation.

The implementation of a GIS has a number of benefits to the project including:

- Efficient access to data through a data sharing framework
- Significant cost savings through use of a central trusted information repository
- Improve the quality assurance and integrity of data
- Efficient management of future requirements.

An effective GIS provides the basis for planning and organising GI activity to deliver maximum benefits both to the project team and to the end users of the service provided.

7.4 Data sources and system development

Following the inception workshop and subsequent internal meetings, work began to develop a desktop GIS to store, analyse and display CO2 sources and storage sites data.

CNTRY_NA_1	CO2_2030_L	CO2_2050_L	CO2_2030_M	CO2_2050_M
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	0	0	
Greece	0	1.6	0	
France	0	0	0	
France	0	0	0	
Austria	0	0	0	
Austria	0	0	0	

Record: 0

FID	Shape	CAP_TOTAL
0	Polygon	18.6287
1	Polygon	81.811809
2	Polygon	89.029215
3	Polygon	323.67717
4	Polygon	315.49619
5	Polygon	141.376061
6	Polygon	11.431558
7	Polygon	148.098588
8	Polygon	235.768742
9	Polygon	25.789614
10	Polygon	52.01236
11	Polygon	312.203089
12	Polygon	323.67717
13	Polygon	323.67717

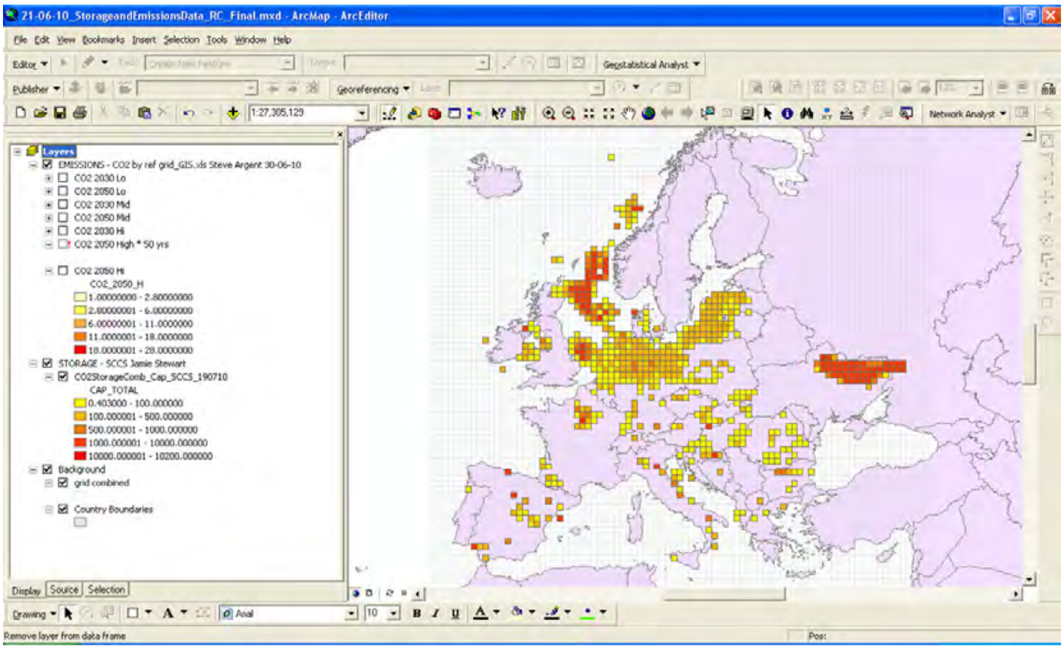
Record: 1

Sample Emissions scenario data table in the GIS, and Storage data table in the GIS

Possible pipeline routes between emissions sources and storage sinks have also been modelled and incorporated into the GIS.

Metadata for the all the datasets is included with the data (see Technical Appendix).

The desktop GIS is based on ESRI's ArcView GIS software, part of the ArcGIS suite of products. This system is function-rich and therefore aimed at specialist users within JRC for advanced analysis and scenario development.



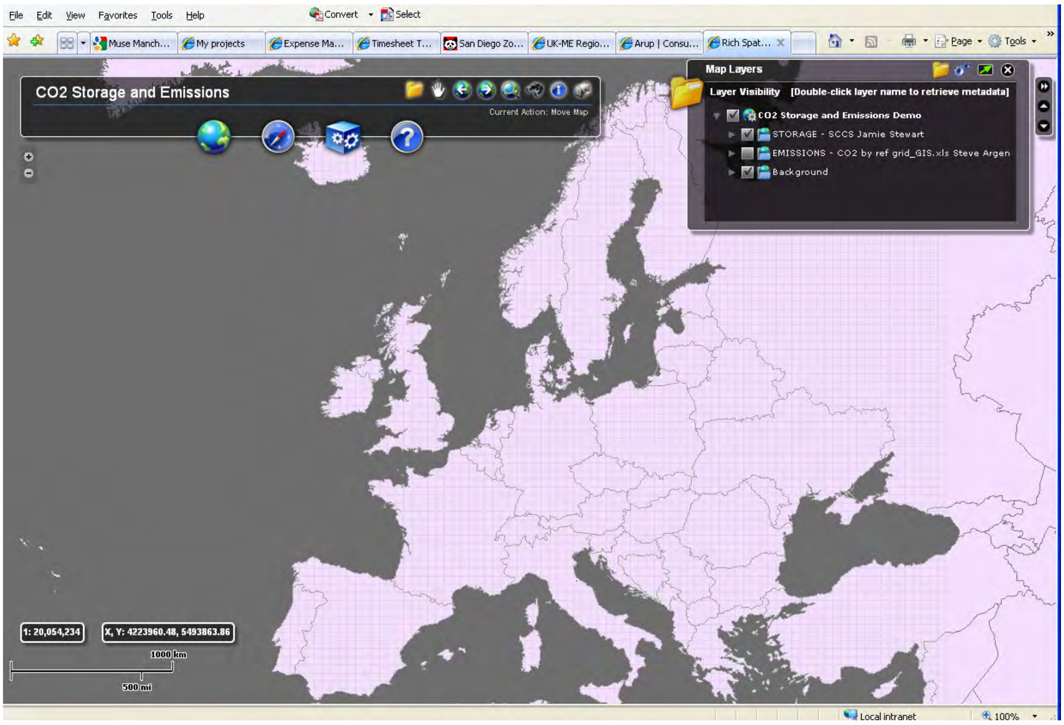
The ESRI ArcGIS EU CO2 Study desktop GIS

A file geodatabase (see Technical Appendix* for glossary) was set up within the GIS to enable efficient storage and access of geographical boundaries and associated emissions and storage data. This is used by both the desktop and online GIS (see below). A 50x50km grid dataset covering Europe, and a dataset containing Member State country boundaries were loaded into the geodatabase to act as base layers upon which to overlay and attach the CO2 data. Each grid cell was given a unique identification number to enable a common means of reference across the project team, and the ability to consistently attach other data as updates were supplied.

Emissions scenarios and storage data was attached to the grid dataset and classified appropriately in discussion with Arup and SCCS colleagues. These discussions aimed to ensure that all values across the whole data range were clearly and appropriately represented using different colours. Incorrect use of classifications on maps can lead to misinterpretation of data and can increase the risk of unsound decision making.

Additionally, a basic online (web-enabled) GIS is currently being developed using ESRI's ArcGIS Server and Adobe Flex technology, mainly for use by non-specialist within the JRC / EC client base to enable simple mapping and interrogation. This will include the same data as the desktop GIS but with much reduced functionality in line with client requirements. A web based system enables wider sharing of project information as most people now have access to browser software and an internet connection.

Online systems can be perceived as more of a risk in data terms than internal desktop systems as there is the potential for inappropriate or illegal access, which is particularly important if the data is sensitive. To limit this risk, access will be controlled by secure logon and standard security protocols (see Technical Appendix).



The prototype ESRI ArcGIS EU CO2 Study online GIS

8 Conclusions and recommendations

1. The defined project objectives have been met, and a regional assessment of CO2 storage potential has been compiled for the EU 27 plus Norway, Switzerland, the Western Balkans and Ukraine, including the North Sea, Irish Sea and Baltic Sea. Whilst this geographical coverage is more extensive than previous studies, it was found that Member states outwith the GeoCapacity study contain minimal additional storage, with the notable exception of the abundant storage claimed in the Scottish offshore and to a lesser extent the Baltic offshore

2. Potential storage is widely spread across Europe. The total storage potential is greater than 122 Giga tonnes, on a "conservative" basis. Present EU emissions are about 1Gt/year, so that many decades of storage exists, if it can be efficiently utilised.

3. Several member states in the centre of Europe, notably Germany, Poland, Czech Republic, are likely to experience shortages of domestic storage. Other member states are likely to have significant within country mismatch between CO2 arising and storage locations.

4. Other than the North Sea, which is relatively well characterised, offshore storage capacities are based on very preliminary assessments. These need to be upgraded in quality and reliability of assessment, or existing data needs to become more publicly available. Important areas include the offshore Baltic, offshore Italy, and coastal Spain. Onshore, improved data quality will be needed in the Donets Basin if that is to be seriously considered. At present the capacities in this report are un-proven, and undertaking injection tests or pilot developments will improve confidence for developers.

5. A coherent and comprehensive database of suitable CO2 storage sites has been developed, though difficulties were experienced in the lack of transparency and auditability of the publicly available GeoCapacity database. Major gaps in data coverage have now been filled, although often at a very preliminary level of assessment. To achieve greater resolution of storage site data, together with improved estimates of storage capacity, then a more specific and open access database plus GIS display needs to be created.

6. An important missing facility for the EU is an easily accessible suite of information on the location of storage capacity onshore and offshore, which will assist planning of CCS projects and increase confidence. This requires an open access web based GIS display to be created. This can be tackled in two steps: firstly a "preliminary GIS" based on published information; second a "simple GIS" informed by a more comprehensive database. The guiding principles are: reliable data and auditable methods of calculation.

    a. A "preliminary GIS" for CO2 storage can be rapidly created by re-working static images published by previous projects and public digital datasets. These will be converted to GIS shapefiles, and detail will be improved with published information around the North Sea rim, northern Germany and Poland. This approach is rapid and cheap, but contains least technical detail. Even so, this will greatly improve the present poorly defined public display of saline formations, structural traps and hydrocarbon fields.

   b. The “simple GIS” will inform a regional overview of the EU. This contains interpretations derived from fundamental data using known and cited methods which can be audited by other users. Five layers of information are desirable, representing: i) political geography, ii) accurate polygon shape files of storage areas in regional saline formations iii) accurate shape files showing storage structures within the regional saline formations iv) accurate shape files showing depleted, current, and future oil and gas accumulations v) qualitative assessment of data quality. Additional layers are also simple such as sites of present day and emissions, gas transport networks, subsurface storage of methane gas, electricity networks. Data input to this GIS can be created progressively, state by state, commencing with the accurate and accessible compilations already available around the North Sea from Denmark, the UK, and Netherlands. Individual states may, in addition, independently produce their own state-based GIS systems, which contain significantly more detail.

7. The best method to create a database for any future GIS of CO2 storage sites is to access and interpret, but not necessarily publish, the fundamental data underlying GeoCapacity. A second method is to request donation, trade, or purchase of the comprehensive surveys made by individual member state geological organisations.

8. It is desirable to keep any GIS maintained and up to date. For example updates on saline formations from Romania and SE France are known but not yet included, Germany will produce an onshore update in 2011, the UK will produce an offshore update early in 2011. Staged updates to the EU CO2 storage GIS are to be expected.

9. To enable confidence in this “simple GIS” display, its continued use, and future evolution and database upgrade, it is important that information can be audited and understood by subsequent users. Information tagged to shapefiles of saline formations or hydrocarbon fields must include the criteria and methods used to define storage sites or regional geological formations, and the assumptions used in producing storage capacity estimates. Such assumptions include technical factors such as mean rock unit thickness, porosity, permeability, storage efficiency, shallowest and deepest depth, density of CO2, temperature, initial and final pressure.

10. A fundamental change is that research and development funding of CO2 storage capacity studies by the Framework Programmes, or by the Commission directly, must include a right for the Commission and its subcontractors to access and reuse the information derived from a study, although a right to publicise the fundamental background information is not needed.

11. A database of future CO2 emissions can be produced, but is highly dependent on assumptions made regarding the energy generation mix. A review of nine existing scenarios from four different sources shows that there is significant variance in predictions of CO2 emissions, leading to carbon capture quantities ranging from 0 (i.e. a 100% renewable electricity scenario) to 912MtCO2/yr. The key variables/assumptions are:

    a. Energy demand

    b. Contribution from renewables and nuclear

  c. % reduction in GHG to be achieved (and the underlying environmental policy)

  d. CO2 price

12. Drawing from the existing scenarios reviewed, and shaped by Arup's view on the future distribution of fossil fuel power plants, High, Medium and Low carbon capture scenarios have been developed. For each scenario, a database of CO2 quantities captured at 2030 and 2050 has been developed, and mapped to the constituent countries included in this study using a 50x50km grid.

13. As power generation from wind and other variable renewable sources increases, the operation of fossil fuel generation is predicted to become more variable, particularly in countries where hydro power cannot balance wind variation. This has implications for CO2 production (peak vs. annual average) – and consequently CO2 transportation infrastructure.

14. When considering different types or 'shapes' for a CO2 pipeline network, initial analysis of a simplified example estimated that ring mains cost approximately twice as much as a trunk main alternative. So, there is a potential high cost premium for security of supply which is unlikely to be accepted. It is most probable that infrequent outages due to maintenance, repair or damage will be managed by short-term venting (or storage) of CO2, though the costs of venting or storage were not included in this assessment.

15. Network optimisation trials found that a range of possible pipe networks could be constructed within 10-15% of the least-cost optimum. This suggests that wide-scale planning to find and implement the optimal solution may not be essential and that there is a beneficial degree of flexibility in the process. It is recommended that this be explored further.

16. A fully-functioning hydraulic model has been used to identify a near-optimum solution. This approach confers several benefits, it:
    a. Avoids unnecessary linearization or simplification
    b. Allows any degree of complexity, so it can be extended to include any built elements in the future and can have boosters and control added
    c. Can be extended to offer multi-variate optimisation
    d. Could be a platform for engineering design in the future

17. Several assumptions have been made in order to undertake the hydraulic modelling aimed at identifying the most cost-effective CO2 pipeline network to link a given set of sources and sinks, including (i) economic cost model, (ii) design velocity and (iii) CO2 density. Some of these will have an appreciable impact upon the costs of the pipeline network, and additional sensitivity work should be undertaken to quantify the impact upon the total cost of the network.

18. If all storage is equally available, the total length (and cost) of CO2 pipeline networks ranges from 6879km (€2074 million) in the 2030 Low CO2 scenario, to 15013km (€12667 million) in the 2050 High CO2 scenario.

19. The network shape and extent of cross-border transportation is highly dependent on the availability/acceptability of onshore storage. If only offshore storage is considered acceptable/available, then network modelling gives entirely different results, show a much greater degree of cross-border transportation, with CO2 transported predominantly northwards to the offshore sinks of the North Sea and the Baltic Sea. The total length (and cost) of CO2 pipeline networks ranges from 8971km (€3434 million) in the 2030 Low CO2 scenario, to 20041km (€19781 million) in the 2050 High CO2 scenario.

20. With network costs 40%-65% higher in the "offshore only" scenario, the availability of onshore storage is a critical judgment. The value of promoting and gaining acceptance of onshore storage could be up to €7000 million.

21. Improving the detail of the economic model would offer a better insight and might change some of the findings. For example, incorporating the cost of developing a CO2 storage site/sink is likely to cause a shift towards a network with more trunk mains leading to a fewer number of sinks. Several other additions could be considered:

    a. pipeline cost premiums for adverse terrain and subsea installation

    b. cost of developing an injection point at a storage site (and the sensitivity of that cost to flow rate)

    c. cross-border costs

    d. design life

    e. cost of large diameter vs. twinned pipes

Appendix A

Network Modelling Itemised Results

A1 Network Modelling Itemised Results

A1.1 2050 High CO2 Scenario

The total cost of the network is €12667 million, the total length is 15013 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 1:

Diameter (inch)	**Length (km)**	**Cost (€ million)**
2.5	100	7.35
4	50	6.54
6	100	19.17
8	653.81	160.50
10	1286.48	413.72
12	46.87	18.21
14	1333.88	539.99
16	1100.06	522.93
18	1438.9	760.50
20	111.80	68.69
22	701.45	453.95
24	473.61	345.33
26	993.06	783.78
28	916.33	792.74
30	784.76	710.36
32	554.55	539.49
34	352.74	362.24
36	390.82	422.67
38	520.03	597.27
40	283.52	338.78
42	320.76	404.37
44	413.69	543.07
46	162.80	224.04
48	186.09	271.76
52	642.09	995.46
56	46.40	79.17
60	357.17	635.48
64	141.42	274.89
72	156.42	332.88
76	90.14	209.01
80	95.71	233.05
Above 80	208.11	599.34

Table 1 Pipeline Diameter Schedule - 2050 High

A1.2 2050 Medium CO2 Scenario

The total cost of the network is €10901 million, the total length is 14334 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 2:

Diameter (inch)	Length (km)	Cost (€ million)
6	100.00	18.02
8	77.20	17.93
10	1653.22	499.40
12	272.19	100.27
14	2437.81	996.44
16	1145.88	544.98
18	778.85	436.51
20	186.13	114.35
22	504.88	330.62
24	837.91	595.18
26	1481.30	1155.26
28	873.27	745.64
30	246.46	224.18
32	659.10	649.34
34	151.22	155.02
36	492.82	536.77
38	300.20	343.81
40	312.13	375.80
42	370.14	469.04
44	39.56	53.25
46	141.69	196.87
52	533.96	849.14
56	187.82	309.14
64	160.85	314.22
68	181.42	368.68
76	50.00	116.07
80	158.11	384.98

Table 2 Pipeline Diameter Schedule - 2050 Medium

A1.3 2050 Low CO2 Scenario

The total cost of the network is €6785 million, the total length is 11775 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 3:

Diameter (inch)	Length (km)	Cost (€ million)
8	608.50	141.30
10	2292.32	700.11
12	145.54	52.36
14	1757.77	720.53
16	984.66	468.71
18	870.87	480.53
20	894.86	536.29
22	591.62	389.00
24	932.82	666.47
26	1084.60	847.46
28	188.22	162.37
30	151.36	136.13
34	323.94	326.69
36	335.51	358.66
38	223.19	260.69
40	25.00	30.01
44	50.00	64.69
46	158.11	220.42
48	156.42	221.84

Table 3 Pipeline Diameter Schedule - 2050 Low

A1.4 2030 High CO2 Scenario

The total cost of the 2030 High CO2 network is €7592 million, the total length is 12384 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 4:

Diameter (inch)	**Length (km)**	**Cost (€ million)**
6	157.01	32.61
8	592.89	137.68
10	1816.62	563.30
12	521.49	187.97
14	1240.36	501.77
16	1200.60	566.27
18	1376.97	753.40
20	459.47	283.87
22	475.04	311.58
24	1096.46	787.55
26	776.49	618.31
28	496.08	229.57
30	350.20	313.39
32	400.35	392.04
34	111.80	117.55
36	151.36	165.25
38	141.42	161.77
42	245.37	306.83
44	223.19	290.42
46	160.85	222.16
52	181.42	285.09
56	50.00	83.84
60	158.11	279.96

Table 4 Pipeline Diameter Schedule - 2030 High

A1.5 2030 Medium CO2 Scenario

The total cost of the network is €4011 million, the total length is 9719 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 5:

Diameter (inch)	Length (km)	Cost (€ million)
4	369.28	46.97
6	292.08	57.69
8	1172.39	279.30
10	2611.01	818.03
12	456.56	171.34
14	1310.82	542.63
16	974.68	393.24
18	1178.46	644.30
20	389.32	232.22
26	262.75	199.34
28	245.37	206.23
30	300.00	271.42
32	156.42	147.99

Table 5 Pipeline Diameter Schedule - 2030 Medium

A1.6 2030 Low CO2 Scenario

The total cost of the network is €2074 million, the total length is 6879 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	**Length (km)**	**Cost (€ million)**
4	599.56	76.04
6	192.94	32.87
8	1333.05	309.55
10	3531.54	1072.81
12	188.83	73.37
14	516.24	219.69
16	90.14	41.87
18	270.37	149.06
22	156.42	98.81

Table 6 Pipeline Diameter Schedule - 2030 Low

A1.7 2050 High CO2 Scenario – Offshore Storage Only

The total cost of the network is €19782 million, the total length is 20041 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost (€ million)
1	50.00	1.64
3.5	200.00	20.63
5	50.00	7.34
6	161.80	33.61
8	1265.72	299.71
10	1599.69	512.54
12	273.59	99.57
14	978.29	404.68
16	1038.00	506.80
18	2399.63	1276.08
20	358.11	216.07
22	918.08	597.39
24	830.12	594.47
26	160.98	125.53
28	855.18	725.15
30	610.41	544.34
32	844.67	820.52
34	421.60	437.04
36	452.00	486.68
38	340.04	385.10
40	120.72	144.87
42	344.58	436.39
44	658.47	881.78
46	467.68	408.53
48	203.35	296.41
52	453.82	701.01
56	276.79	457.83
60	843.18	1504.56
64	681.30	1312.65
68	250.88	520.34
72	250.00	538.82
76	323.61	745.40
80	427.20	1017.45
above 80	931.74	2720.24

Table 7 Pipeline Diameter Schedule - 2050 High

A1.8 2050 Medium CO2 Scenario – Offshore Storage Only

The total cost of the network is €16439 million, the total length is 18635 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost ($ million)
3.5	200.00	27.51
4	50.00	7.86
5	50.00	9.79
8	1190.61	377.21
10	1266.98	520.69
12	387.28	175.83
14	2627.29	1413.92
16	1400.62	867.29
18	1092.39	795.13
20	379.68	302.13
22	680.02	595.43
24	413.20	391.33
26	1120.19	1145.30
28	629.58	703.67
30	722.74	858.16
32	466.29	602.87
34	120.72	161.66
36	448.17	643.49
38	705.88	1092.70
40	50.00	78.94
42	391.42	664.78
44	357.17	636.61
46	50.00	93.55
48	276.79	529.39
52	813.89	1668.64
56	681.30	1514.78
60	300.88	729.06
64	100.00	251.73
68	850.81	2349.46
72	313.15	925.88
76	176.43	535.23
above 80	321.45	1248.04

Table 8 Pipeline Diameter Schedule - 2050 Medium

A1.9 2050 Low CO2 Scenario – Offshore Storage Only

The total cost of the network is €9560 million, the total length is 13746 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost ($ million)
2.5	50.00	5.40
8	372.39	115.28
10	3414.07	1398.79
12	124.81	59.36
14	884.05	482.03
16	1520.48	988.35
18	549.18	403.27
20	352.79	284.51
22	817.58	720.29
24	538.21	507.30
26	610.02	653.74
28	595.24	687.28
30	303.35	360.87
32	297.50	379.20
34	1091.70	1501.85
36	253.95	369.23
38	158.11	239.83
40	100.88	165.28
42	50.00	85.62
44	527.20	934.76
46	273.61	511.90
48	313.15	601.56
52	226.43	453.77
60	61.85	145.20
68	259.60	692.68

Table 9 Pipeline Diameter Schedule - 2050 Low

A1.10 2030 High CO2 Scenario – Offshore Storage Only

The total cost of the network is €11206 million, the total length is 14908 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost ($ million)
8	793.66	245.69
10	2806.63	1172.18
12	778.83	380.25
14	992.11	544.20
16	785.32	507.30
18	1378.96	977.45
20	338.74	272.10
22	204.78	180.35
24	1058.96	1011.43
26	435.18	459.50
28	161.80	182.42
30	610.02	713.78
32	113.79	147.36
34	972.03	1330.95
36	89.56	129.36
38	709.94	1104.77
42	556.42	933.30
44	308.11	543.62
46	100.88	183.99
48	150.00	290.87
52	700.81	1459.74
56	489.58	1100.84
60	50.00	121.66
68	61.85	165.27
76	259.60	782.87

Table 10 Pipeline Diameter Schedule - 2030 High

A1.11 2030 Medium CO2 Scenario – Offshore Storage Only

The total cost of the network is €5747 million, the total length is 10829 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost ($ million)
6	495.84	130.59
8	1308.50	410.07
10	1975.41	822.09
12	248.17	123.89
14	1249.95	699.65
16	703.07	450.21
18	1194.62	884.28
20	1091.70	897.63
22	347.50	305.00
24	150.00	143.89
26	197.67	208.98
28	304.83	348.33
30	477.20	558.51
32	176.43	228.52
34	0.00	0.00
36	586.76	841.80
44	61.85	108.99
48	259.60	500.16

Table 11 Pipeline Diameter Schedule - 2030 Medium

A1.12 2030 Low CO2 Scenario – Offshore Storage Only

The total cost of the network is €3434 million, the total length is 8971 km and the itemised pipe diameter Vs length/cost schedule is shown in Table 6:

Diameter (inch)	Length (km)	Cost ($ million)
4	445.84	75.60
6	50.00	11.45
8	1492.40	460.73
10	3070.53	1236.08
12	1089.78	541.76
14	372.07	206.49
16	425.11	272.88
18	790.14	575.50
20	373.61	300.26
22	418.87	380.28
26	61.85	62.33
28	111.80	129.35
30	197.80	234.92
32	70.71	90.41

Table 12 Pipeline Diameter Schedule - 2030 Low

Appendix B

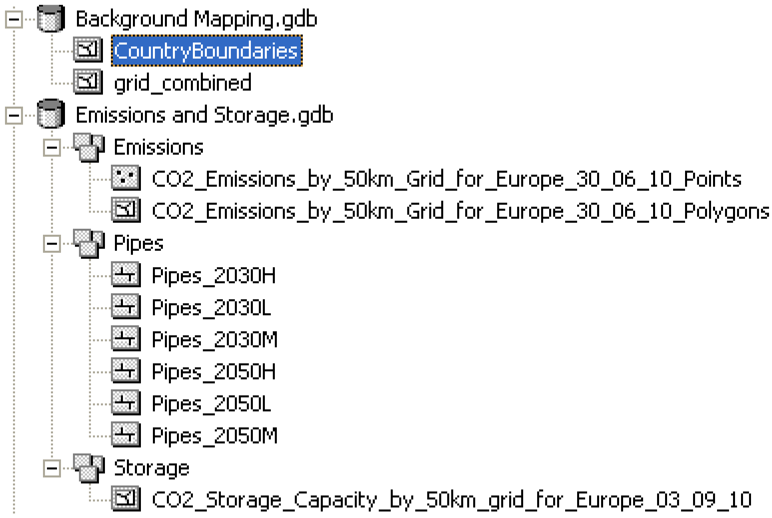
GIS Technical Data

B1 GIS Technical Data

2.1 Data

2.1.1 Format

The data is supplied in an ESRI file geodatabase and can be used for both the desktop and web-based GIS (see 3.2). The file names and structure are as below:



- Background Mapping.gdb
  - CountryBoundaries
  - grid_combined
- Emissions and Storage.gdb
  - Emissions
    - CO2_Emissions_by_50km_Grid_for_Europe_30_06_10_Points
    - CO2_Emissions_by_50km_Grid_for_Europe_30_06_10_Polygons
  - Pipes
    - Pipes_2030H
    - Pipes_2030L
    - Pipes_2030M
    - Pipes_2050H
    - Pipes_2050L
    - Pipes_2050M
  - Storage
    - CO2_Storage_Capacity_by_50km_grid_for_Europe_03_09_10

2.1.2 Metadata

All relevant information on the dataset is included in the INSPIRE formatted metadata, and is accessible via the desktop GIS (see below) and ArcCatalog.

INSPIRE format metadata was created with ESRI's metadata editor available at:

http://www.b-inspired.ie/5-downloads.asp

More information on the INSPIRE metadata specification is here:

http://inspire.jrc.ec.europa.eu/index.cfm/pageid/101

2.1.3 Emissions Scenario Data

Emissions data in megatons (MT) (see WP3 for data development methodology) was received from Steve Argent within Arup and aggregated and attached to the 50km grid covering Europe (see metadata). The data is classified and symbolised as below:

CO2 captured in MT/yr

- ● 1 - 2
- ● 2 - 4
- ● 4 - 8
- ● 8- 14
- ● 14 - 28

The original gridded version of the data is also supplied.

2.1.4 Storage Data

Storage Data in megatons (MT) (see WPs 1 and 2 for data development methodology) was received from our SCCS partners in Edinburgh and attached to the 50km grid (see metadata). The data is classified and symbolised as below:

CO2 Storage in MT

- 🟨 0 - 100
- 🟧 100 - 500
- 🟧 500 - 1000
- 🟧 1000 - 5000
- 🟥 5000 - 10000

2.1.5 Pipeline Data

Pipeline Data was received from Pipeline Simulation Ltd and based on the 50km grid centroid coordinates with emissions and storage data attached. (see metadata).

The data is classified and symbolised as below:

— Pipelines

2.1.6 Other Data

Background mapping consists of the 50km grid for Europe and also Country Boundaries (see metadata). They are classified and symbolised as below:

- □ Europe Grid
- 🟪 Country Boundaries

2.2 GIS Applications

2.2.1 Specifications and Assumptions

Although no detailed specification exists for the GIS deliverables, and there are therefore no sign-off criteria per se, some requirements and assumptions for the applications were obtained during discussions at the Petten meeting on 16th July:

Deliverables:

- File Geo-database with all data
- Discovery level dataset metadata
- ArcGIS Mxds (version 9.3.1) with relative pathnames to the file-geodatabse
- ArcGIS server config and code that is used for developing the web GIS

Assumptions:

- The JRC team will be responsible for receiving the mxds and metadata and publishing these to JRC staff
- The mxds will be created in ArcGIS 9.3.1 format
- JRC users will be able to use ArcGIS and use the mxds
- ArcGIS Server version 9.3.1 will be used.
- The application will be developed with the FLEX API
- A file-geodatabase will be used to store the data
- Users will be using IE as the standard browser with Flash player installed
- The JRC will be responsible for setting up the ArcGIS Server application internal to their application
- The JRC will be responsible for providing users with access to the ArcGIS Server application once it is handed over
- No temporal database or analysis functionality is required by JRC or the EC
- The web application will include basic functionality. This will include:
    - Zoom in / out
    - Pan
    - Identify
    - Toggle layers
    - Access to metadata (currently desktop application / ArcCatalog only)

2.2.2 Desktop GIS

The desktop GIS was developed using ESRI's ArcGIS version 9.3.1. This is delivered 'out of the box' with no customisation other than the file geodatabase described earlier. No detailed instructions are provided as this is to be used by JRC or other EC personnel only who are familiar with its operation.

The system requirements can be viewed at:

http://wikis.esri.com/wiki/display/ag93bsr/ArcGIS+Desktop

2.3 Web-based GIS

2.3.1 About the Web-based GIS

The Web Viewer application was written using Adobe Flex technology. It allows for a slick, modern user interface on top of a map, which allows users to intuitively identify features on the map, to gain knowledge about information for a particular feature. As Flex uses Flash technology, it is important that end users have a copy of Adobe Flash on their PCs. Our integration testing was performed using Adobe Flash 10 – the latest version – and we are assuming that all end users will have this version on their PCs.

The system works by a 'Map Service', which resides on the central server. When the user makes a query for new map, or information about a feature on the map, a message is sent to the server. It responds by sending back a set of features, which are then recomposed in the client's browser, again using Flash technology.

See ESRI's website for the system requirements:

http://www.esri.com/software/arcgis/arcgisserver/common-questions.html

2.3.2 Installation of the Web-based GIS

Provided with these Appendices are a set of files that need to be deployed on a web server. The following needs to be installed as a pre-requisite:

Arup will provide a set of files that need to be deployed on a web server. The following needs to be installed as a pre-requisite:

- Internet Information Server
- ArcGIS Server 9.3.1.

In our configuration, both need to be installed on the same machine.

For clients, as the software uses Flash technology, it’s important that client computers are able to consume flash. We recommend Adobe Flash 10 on client machines.

IIS configuration

In this step, you will be copying the web site into the relevant folder on the server, and instructing the web server to be able to display files to the end user.

Steps to be undertaken are:

1. Open Administrative Tools > Internet Information Services Manager
2. In the list of ‘sites’, open the Default Web Site
3. Right-click> Add Virtual Directory, and call it ‘CO2’
4. Copy the ‘CO2’ folder (website installation package, included) into the ‘CO2’ folder onto your web server. (Importantly, index.html should be included, as should the included SWZ files.) This should be copied as c:\inetpub\wwwroot\CO2.
5. Check that there is a server

GIS File installation

There are two separate sets of contents that need to be installed on the ArcGIS Server: the project file (MSD) and the geodatabase (a folder containing data files). In effect, the MSD points to the geodatabase, and contains information on rendering. ArcGIS Server needs to be set up with folder shares thus:

\\webserver\mxds (contains MXD or MSDs)

\\webserver\fileGDB (contains the geographic database)

1. Create folders on the server called ‘mxds’ and ‘fileGDB’. (They could be from the root, so c:\mxds would do. Crucially, make sure they are shared with those names.)
2. Copy the msd file into the ‘mxds’ share.
3. Copy the Geodatabase folders (these are folders that end with ‘.gdb’) into the \fileGDB share.

The MSD file needs to see the \fileGDB folder as a network share, hence the reason why it is important that folders are shared that way.

Web application configuration

As the application will need to be deployed on different servers, it is important that the configuration file is adjusted to reflect this.

1. Copy 'config.xml' in your favourite text editor
2. Search for 'glogis02' and replace with the name of your server
3. Save the config.xml file.

ArcGIS Server configuration

A new web service needs to be created that allows maps to be displayed to the end user. To do this, you must have administrative rights to ArcGIS Server.

1. Start up ArcGIS Server manager. (This may be http://yourservername/ArcGIS/Manager.)
2. Log in as administrator.
3. Under 'services', select 'Add New Service'.
4. Add a new service under the name '212043_CO2_Storage_and_Emissions'.
5. Ensure it is set as a Map Service in the menu.
6. Click Next.
7. Click the small folder icon next to 'Map Document', and select the MSD/MXD file that you copied into the \\webserver\mxds folder previously. (It's important that you use the '\\webserver\mxds\...' path as opposed to 'c:\mxds'.)
8. Ensure the output directory is set – this should be the default setting that you used when you installed ArcGIS Server.
9. Click Next.
10. In the next page, leave the defaults switched on – Mapping, KML, Enable Web Access, Map, Query Data should all be checked 'on'.

11. Click Next.

12. Leave the services as ‘Pooled’.

13. Click Next.

14. Leave the next page as it is.

15. Finally, the summary screen will appear, informing you that you are about to create a new web map service. Leave ‘yes, start service now’ selected.

16. Click Finish.

At this stage, you should have a working copy of the database, project file, and the application itself in the relevant directory space. Check this by starting up http://yourservername/CO2.