ISSN 1831-9424

European Commission

Shaping the future CO_2 transport network for Europe

Tumara, D., Uihlein, A., Hidalgo Gonzalez, I.

2024

Joint Research Centre

EUR 31835 EN

Contact information
Name: Drazen Tumara
Address: European Commission, Joint Research Centre (JRC), P.O. Box 2, NL-1755 ZG Petten, the Netherlands
Email: Drazen.TUMARA@ec.europa.eu
Tel.: +31 (224) 56-5237

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC136709

EUR 31835 EN

PDF ISBN 978-92-68-12059-0 ISSN 1831-9424 doi:10.2760/582433 KJ-NA-31-835-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Center, Tumara, D., Uihlein, A. and Hidalgo Gonzalez, I., *Shaping the future CO2 transport network for Europe*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/582433, JRC136709.

Contents

Abstract

Carbon capture, utilisation and storage (CCUS) can contribute to the achievement of climate neutrality, especially for hard-to-abate sectors and to remove carbon for any residual emissions. For the successful deployment of CCUS, it is necessary to develop infrastructure for transporting captured CO_2 from its sources to suitable storage sites.

This study estimates the evolution of the extent and the investment requirements of the trans-European CO_2 transport network from 2025 to 2050. By 2050, the European CO_2 pipeline network could reach a considerable length up to 19 000 km and requires investment of between EUR 9.3 billion and EUR 23.1 billion. The extent and the cost of the network can be reduced by developing storage capacities in regions where current capacities are insufficient (e.g. southern and eastern Europe) to avoid transporting CO_2 over long distances. To reduce investment costs, the planning and development of storage capacities and CO_2 capture projects should be carefully coordinated.

In the early phase of the CO_2 transport network development, the EU lacks commercially proven CO_2 storage capacity. We should develop a European CO_2 storage atlas to provide comprehensive and accurate information on storage potential across the continent. The CO_2 transport network has a significant number of cross-border connections, reflecting its international character. To facilitate cross-border transport, CO_2 quality standards for transport and storage are essential.

International coordination and collaboration will be crucial for the successful, cost-optimised development of the CO_2 infrastructure.

Acknowledgements

The authors wish to thank our colleague Guillermo Martinez Castilla and former colleague Zoi Kapetaki for their contribution to the study, as well as Catriona Black for review and proofreading.

We thank our colleagues Chris Bolesta, Alexandre Dedo, Barbara Diz, Johanna Fiksdahl, Katrien Prins and Ruud Kempener (all DG ENER), Daniel Kitscha (DG CLIMA) for their valuable comments, insights, and support during the development of this report.

Authors

Tumara Drazen, European Commission, Joint Research Centre (JRC), Petten, Netherlands

Uihlein Andreas, European Commission, Joint Research Centre (JRC), Petten, Netherlands

Hidalgo González Ignacio, European Commission, Joint Research Centre (JRC), Petten, Netherlands

Executive summary

Policy context

The world has committed itself to limiting global warming well below 2°C and ideally no more than 1.5°C. The EU aims to reduce greenhouse gas emissions by 55% by 2030 and has set high ambitions for 2040. Carbon capture and storage (CCS) will play an important part in reaching our climate targets. The deployment of CCS technologies will have to increase drastically at a global level as well as in the EU. Current studies estimate that in the EU, at least 50 million tonnes of CO_2 will have to be captured, transported and stored per year by 2030, and up to 250 million tonnes by 2050.

To enable the deployment of CCS in Europe at a larger scale, we need networks comprising primarily of pipelines and ships for transporting captured CO_2 from its sources to suitable storage sites. This study focuses on the CO_2 transport infrastructure needs and assesses the evolution, extent, and investment requirements of a trans-European CO_2 transport network. It has been conducted at the request of, and in close collaboration with, the Directorate-General for Energy (DG ENER) in support of the Industrial Carbon Management Strategy.

Key conclusions

The CO_2 transport infrastructure is a crucial factor and a key enabler of the successful large-scale deployment of CCUS. The development of a European CO_2 pipeline infrastructure will be challenging during the early phases of CCS deployment, before 2030, and alternative forms of CO_2 transport should also be explored.

The EU lacks commercially proven CO_2 storage capacity in the early phase of CCS deployment. Coordination efforts are needed to identify suitable CO_2 storage locations. An updated European CO_2 storage atlas should be developed which will provide comprehensive and accurate information on storage potential across the continent.

The future CO_2 transport network will exhibit a highly international character. Therefore, common quality standards for CO_2 for its transport and storage are essential.

Investment costs could be reduced by developing storage capacities in areas where identified capacity is insufficient (e.g. southern and eastern Europe) to avoid transport of the captured CO_2 over long distances, for example to the North Sea region.

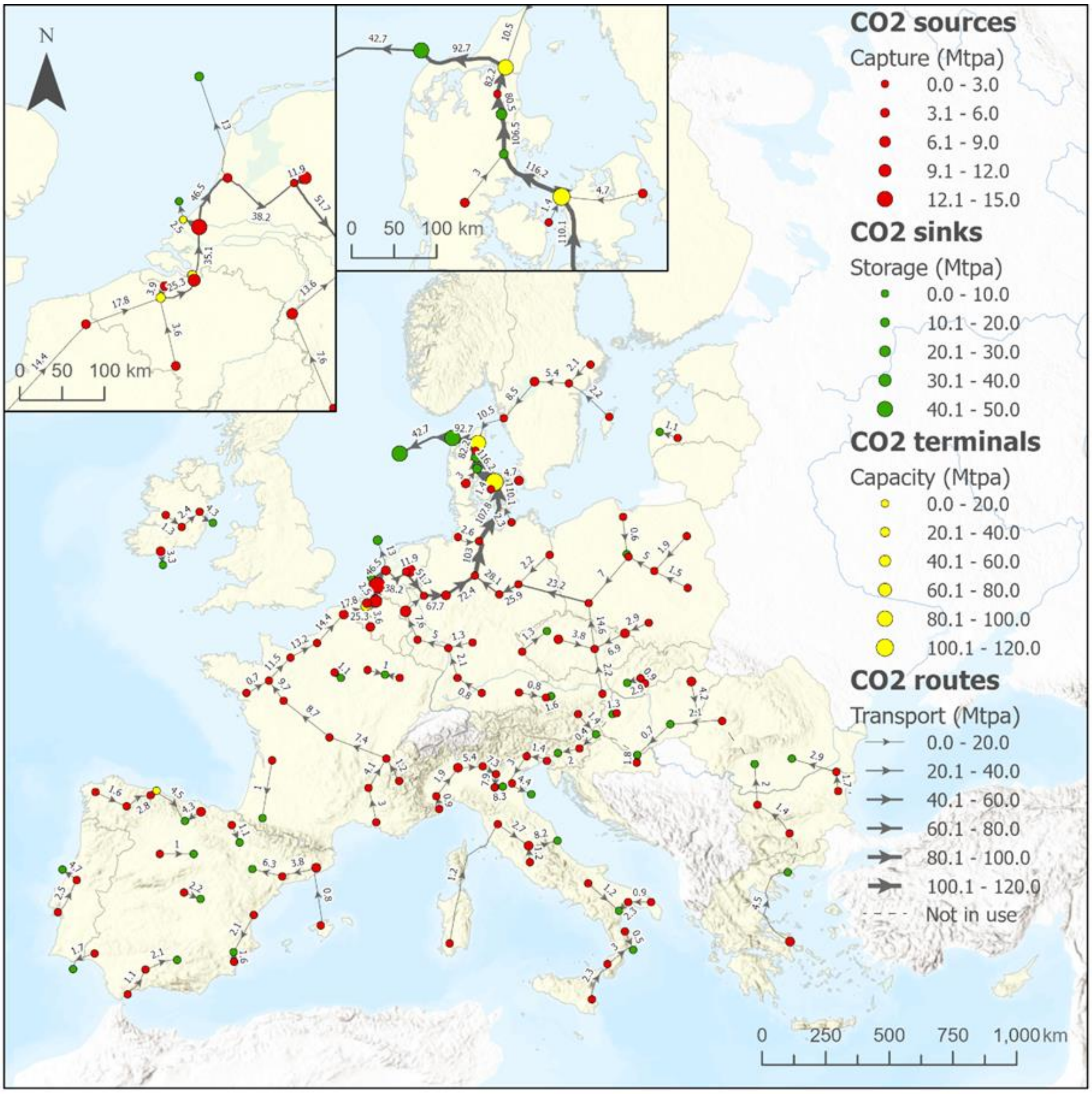
International coordination and collaboration is crucial for the successful, cost-optimised development of the CO_2 infrastructure.

Main findings

This study identified around 100-120 potential CO_2 capture clusters and about 100 storage sites throughout Europe. Using a model, and assuming eight different scenarios, the optimal CO_2 transport network from an investment cost perspective has been derived, spanning the years from now up to 2050.

The study shows that the future European CO_2 transport network could reach a length of 6 700-7 300 km by 2030, and might extend to between 15 000 and 19 000 km by 2050. Its deployment could cost between about EUR 6.5 billion and EUR 19.5 billion by 2030, rising to between EUR 9.3 billion and EUR 23.1 billion in 2050. The figure below shows an example of the potential future CO_2 transport network in 2050 according to one of the eight scenarios.

Figure 1. Potential CO_2 transport network in 2050 according to scenario C1



Source: JRC, 2024

The CO_2 transport network grows fastest between 2030 and 2040, except for two scenarios where we see a large increase of CO_2 captured between 2040 and 2050 following the results of two different Commission models: CTP 2040 and Fit-for-55.

Related and future JRC work

The JRC will perform in the future, several updates of this study. Firstly, we will continue to collect information about announced and planned CO_2 capture and storage projects, as well as CO_2 transport projects, to keep our CCS project database up to date. In addition, we will strive to improve data on potential CO_2 storage locations; and hopefully, a new European CO_2 storage atlas can be developed to facilitate this assessment.

Further, the JRC will include more modes of CO_2 transport in the modelling, primarily with more information on shipping, and update CO_2 transport investment costs with the latest information (e.g. transport by rail and road as well as barges to connect smaller emitters to the CO_2 backbone network).

As part of future work, we are considering analysis of the most suitable locations for Direct Air capture (DAC) facilities.

Quick guide

This study assesses the evolution, extent and costs of a future European CO_2 transport network that will enable transport of CO_2 from capture sites to potential CO_2 storage facilities. The study uses a cost-optimisation model to connect CO_2 capture and storage sites for the years 2025 to 2050 by means of pipelines and ships. The study identifies various uncertainties such as the amount and location of CO_2 capture, and the capacity and development of storage sites. In order to assess the effect of those uncertainties, the study uses eight different scenarios with varying underlying assumptions. The main conclusions of the study are robust and supported by scenario analysis.

1 Introduction

During the COP 21 Climate Conference in Paris in 2015, policymakers reached a historic agreement on climate action. The objective of this agreement is to keep the global average temperature increase well below 2°C above pre-industrial levels and to make efforts to limit the temperature rise to 1.5°C.

To achieve the goal of limiting global warming below 2°C, it is necessary to increase the installed Carbon Capture and Storage (CCS) capacity significantly, from approximately 40 Mtpa currently to over 5 600 Mtpa by 2070 worldwide (International Energy Agency, 2019). The latest estimate of the International Energy Agency (IEA) is even higher, at 6 200 Mtpa by 2050. This estimate forms part of the Net Zero Emissions by 2050 Scenario (NZE), a normative scenario that shows a pathway for the global energy sector to achieve net-zero CO_2 emissions by 2050 and to limit global warming to 1.5°C (International Energy Agency, 2022). Both projections made by the IEA consider Carbon Dioxide Removal (CDR) and Carbon Capture and Utilisation (CCU).

Scenarios that align with the 1.5°C target in the European Commission's (EC) strategic long-term vision rely on the implementation of CCS and CO_2 removal techniques to attain climate neutrality (European Commission, 2018). These measures are essential for effectively combating climate change in a manner consistent with the objectives outlined in the Paris Agreement.

The Green Deal Industrial Plan has identified CCS technologies as a key sector in achieving the climate neutrality objectives of the EU. CCS offers a viable solution for addressing emissions in challenging sectors, such as energy-intensive industries and energy production facilities, which are considered hard-to-abate (European Commission, 2023). In addition to mitigating emissions from these sectors, the plan acknowledges that there will be certain emissions that cannot be eliminated entirely. In such cases, it will be necessary to capture these emissions directly from the atmosphere and transport them to permanent storage. This approach ensures that even the emissions that cannot be mitigated are effectively captured and stored, contributing to overall emission reduction efforts and the attainment of climate neutrality goals set by the EU.

By recognising the importance of CCS technologies and their role in addressing emissions in difficult sectors, the Green Deal Industrial Plan aims to foster the development and implementation of CCS solutions as a vital component of achieving climate neutrality within the European Union. Today, most elements of the CCS chain of technologies (CO_2 capture, transport and storage) have already been commercialised, albeit at a scale much smaller than that which is ultimately required. To enable the widespread implementation of CCS in Europe, it is necessary to develop networks comprising pipelines and ships for transporting captured CO_2 from its sources to suitable storage sites.

Initially, these networks would be constructed at the regional or national level and designed to accommodate the transportation needs of multiple CO_2 sources. By capitalising on economies of scale, they can facilitate the connection of additional CO_2 sources to sinks throughout the pipeline's lifetime. In the long term, these integrated networks can be expanded and interconnected across Europe, connecting CO_2 sources with distant storage sites. This could result in a comprehensive trans-European network, akin to the existing networks for electricity and natural gas transmission.

The study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe (Carbon Limits AS and DNV AS, 2021) concluded that there are no showstoppers for transporting CO_2 in the gaseous phase in the existing onshore and offshore pipelines and that CO_2 transport in dense phase is technically feasible in more than half of offshore pipelines and in a very small portion of the onshore pipelines. In addition, based on analysis of half of the total offshore pipeline length in Europe (16 300 km) and approximately 30% of the onshore length (41 700 km), around 40% of the offshore and 25% onshore pipeline length could be reused, provided that more detailed analyses and/or tests produce positive results.

However, it is important to note that the physical properties of CO_2 differ from those of natural gas. There is a possibility that the pipelines used for CO_2 transport would need to operate under different conditions compared to most existing pipelines. Additionally, they could be required to operate with low levels of impurities, including corrosive substances like water, which can pose challenges for conventional pipeline materials. Also, existing gas infrastructure is not necessarily located in the right place for transporting CO_2 in the future. This emphasises the necessity for new infrastructure to be capable of accommodating EU-wide requirements associated with CO_2 transportation. Despite all the above-mentioned issues, the large-scale transportation of CO_2 by pipeline is an established industrial process in the USA with more than 7 000 km of CO_2 pipelines in operation for almost four decades (ZEP, 2020).

The theoretical quantity of CO_2 that can be stored permanently in most of the EU was estimated to amount to nearly 72 Gt (Consoli and Wildgust, 2017; Global CCS Institute, 2016; Vangklide-Pedersen, 2009). By contrast, estimates in the UK and Norway show potential of around 78 Gt (Pale Blue Dot, 2016) and 80 Gt (Norwegian Petroleum Directorate, 2019), respectively. The estimation of storage potential is under way in Denmark, where the first cross-border carbon capture and storage was achieved by capturing and shipping CO_2 from Belgium and storing in a depleted hydrocarbon field beneath the Danish North Sea (Carbon Capture Journal, 2023). However, to facilitate EU-wide network planning and deployment, it is necessary to estimate as far as is possible all EU CO_2 storage capacities and to harmonise different national methodologies for more precise estimations. This harmonisation facilitates the update of the European storage atlas, providing comprehensive and accurate information on storage potential across the continent. By standardising methodologies and data collection approaches, the updated storage atlas would enhance the understanding of storage capacities and support the development of CCS infrastructure (including transport) throughout Europe.

Over the years, there have been varying perspectives on the potential evolution of CO_2 infrastructure in Europe. Some views have emphasised the establishment of a regional or national network of CO_2 infrastructure, initially focusing on connecting CO_2 capture sources to nearby storage sites. This approach advocates the gradual expansion of infrastructure as more sources and storage sites become operational. It suggests leveraging existing pipelines and facilities when feasible, and gradually expanding the network as demand and project requirements increase. Other perspectives have envisioned a more integrated and interconnected trans-European CO_2 infrastructure, similar to the existing networks for electricity and gas. This view emphasises the potential benefits of interconnecting CO_2 sources and storage sites across different countries, allowing for the cost-effective transportation and storage of captured CO_2 on a broader scale.

Considering their inclusion in the Emissions Trading System (EU ETS) and an existing legal framework[1] for the environmentally safe geological storage of CO_2, a number of energy-intensive 'hard-to-abate' sectors (e.g. the cement industry) are increasingly developing investment plans in CO_2 capture, which are expected to reach a positive economic return before 2030, based on projected carbon prices. For CO_2 capture, Europe holds a leading position, but the unavailability of operating storage sites is a bottleneck that needs to be addressed in order to allow the decarbonisation of hard-to-abate industries. In addition, the bottleneck could be even more significant in the future, since the lead times

[1] Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 ("CCS Directive")

for developing the storage sites are much longer than those for capture facilities, making it critical to reduce project lead times (International Energy Agency (IEA), 2023).

The EU would need at least 50 Mtpa of CO_2 storage capacity available by 2030 to meet demand associated with carbon capture projects under development as outlined in the Net-Zero Industry act proposal (European Commission, 2023). Furthermore, to realise EU climate neutrality by 2050, the deployment of CO_2 capture facilities would need to occur at an even larger scale. The availability of sufficient storage capacity is essential to support the development and expansion of decarbonisation initiatives, allowing industries to capture and store their CO_2 emissions effectively.

However, the distribution of CO_2 storage sites and capacities across Europe is not evenly spread. As a result, it will be necessary to develop storage sites beyond the North Sea and construct an extensive pipeline infrastructure spanning several EU Member States (MS) and neighbouring countries. This infrastructure will be crucial in cases where countries do not possess sufficient CO_2 storage potential or when storage is not feasible due to various reasons, such as a lack of public acceptance.

The construction of such a pipeline network would connect regions and countries, allowing for the transportation of captured CO_2 from areas with high emissions to suitable storage sites in regions where storage is possible and viable. By establishing these cross-border pipelines, countries can overcome limitations related to their individual storage capacities and ensure the effective transport of CO_2 and total cost reduction. The development of such a trans-European network would require coordination, collaboration and harmonisation among countries, companies and other stakeholders.

In the EU, there are two main support measures dedicated to CCS. The EU supports eleven large-scale CCS and CCU projects through its large funding programme for the demonstration of innovative low-carbon technologies, the Innovation Fund. Another eight projects were selected for grant agreement preparation[2]. Additionally, in November 2023, the Commission adopted the 1st list of Projects of Common Interest (PCIs) and Projects of Mutual Interest (PMIs) under the revised TEN-E Regulation[3], which includes fourteen CO_2 transport network projects[4].

The objective of this analysis is to update a previous JRC study on the evolution of the extent and the investment requirements of a trans-European CO_2 transport network (Morbee, Serpa, and Tzimas, 2012). The analysis has been conducted at the request of, and in close collaboration with, the Directorate-General for Energy (DG ENER), in support of the Industrial Carbon Management Communication planned for the beginning of 2024. In parallel, DG ENER initiated a study titled 'EU regulation for the development of the market for CO_2 transport and storage' with the objective of analysing regulatory framework options to facilitate the development of CO_2 transport and storage infrastructure, as well as business models in Europe (ENTEC, 2023).

This study primarily focuses on CO_2 transport via onshore and offshore pipelines and suitable maritime ships, similar to those used for transporting liquefied natural gas (LNG) and liquefied petroleum gas (LPG). The focus is on the evolution, extent and investment needs of the transport infrastructure which will play a major role in the European CO_2 transport network. This network will

---

[2] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/large-scale-calls_en

[3] Regulation (EU) 2022/869 (https://eur-lex.europa.eu/eli/reg/2022/869/oj)

[4] https://energy.ec.europa.eu/system/files/2023-11/Annex%20PCI%20PMI%20list.pdf List of PCIs: CO2 TransPorts, Aramis, ECO2CEE, Bifrost, Callisto, CCS Baltic Consortium, Delta Rhine Corridor, EU2NSEA, GT CCS Croatia, Norne, Prinos, Pycasso. List of PMIs: Northern Lights and Nautilus CCS.

act as the backbone network for CO_2 transportation and may eventually facilitate connections with smaller emission sources through alternative transportation methods, e.g. truck, rail and barge.

The study encompasses EU territory, with Norway and the UK included solely in relation to storage sites due to their relative importance. The time frame extends from 2025 to 2050, with additional snapshots for the years 2030 and 2040. Considering the extensive spatial and temporal coverage, it is important to regard the results as indicative in nature. They represent a first 'order of magnitude' estimate of the extent of the CO_2 network and investment required, as well as an insight into its international character.

The results are highly dependent on the underlying assumptions made throughout the analysis, particularly considering the long-term perspective, uncertainties surrounding CCS deployment rates and timelines, limited availability of reliable data on CO_2 storage sites, and the variability associated with pipeline and ship construction.

The remainder of this report is structured as follows: Section 2 presents the methodology used in this study which relies on the previous study with significant enhancements and updates according to new information. This methodology represents a basis for future updates and can be used with new datasets and under a different set of assumptions. Section 3 presents the scenarios used in this study with various assumptions regarding the amounts and locations of CO_2 captured and stored. Section 4 gives a comprehensive overview of the results of the analysis. This includes graphical representations depicting the evolution and extent of the CO_2 network, and its international character. Please note that results will also be available in the Energy and Industry Geography Lab (EIGL) (https://ec.europa.eu/energy-industry-geography-lab). In addition, Section 4 presents the key figures in terms of investment requirements for the deployment of the trans-European CO_2 transport network. Finally, the main conclusions derived from the analysis are summarised in Section 5.

2 Methodology

The objective of this analysis is to identify the optimal CO_2 transport network in Europe and track its evolution over time. The term 'optimal' refers to the determination of a network configuration that transports predetermined volumes of CO_2 to suitable storage sites at the lowest possible investment cost. Previous studies accounted for emissions captured only from the power generation sector. Capturing the emissions from other industries, accounted for in this update of the study, will obviously increase the number of CO_2 emitters and CO_2 that needs to be transported, and hence lead to an expanded CO_2 transport network compared to the previous study. Within the current analysis, cross-border CO_2 transport is considered only when it proves to be a cost-minimising solution.

2.1 Methodology structure

The methodology employed in this analysis comprises four important steps:

a. identification and clustering of CO_2 sources and sinks,

b. assumptions about the evolution of captured CO_2 emissions and storage capacities,

c. identification of potential routes between nodes,

d. selection of the optimal network and evolution over time.

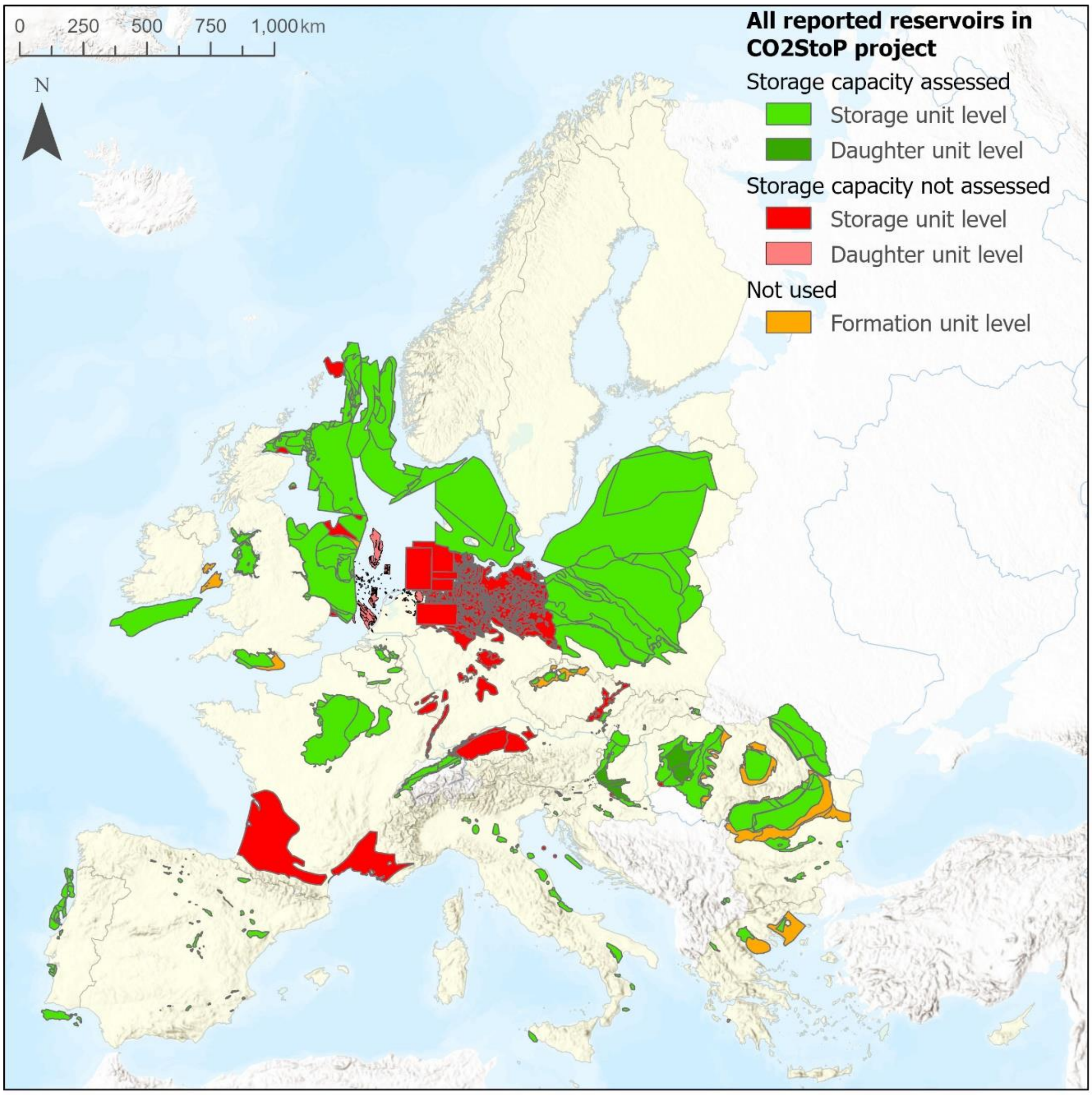
2.1.1 Identification and clustering of CO_2 sources and sinks

The CO_2 source locations indicate the sites where CO_2 emitters are situated and where carbon capture technologies can be implemented. These sources can be classified into two categories based on the sector from which the CO_2 originates: power generation and process-related CO_2. Power generation sources are associated with the generation of electricity and heat, while process-related CO_2 sources represent energy-intensive industry facilities, e.g. metal production, mineral products and the chemical industry.

The locations of the CO_2 sources were obtained using the ETS registry database (EUTS, 2022) which provides verified emissions data for 2019. The emissions data is categorised based on the source, specifically fuel combustion and processes, according to information from Eurostat's air emission inventories: Greenhouse gas emissions by source sector - table env_air_gge (Eurostat, 2022). Additionally, depending on the scenario, the locations of announced CCS projects are identified and included in the list of CO_2 sources. If CCS projects are identified at the same location as the CO_2 sources from the ETS registry database, the latter are replaced with the CCS project locations.

The locations and characteristics of potential CO_2 storage sites are obtained from the EU-funded CO2StoP project database, CO_2 Storage Potential in Europe - Project No. ENER/C1/154-2011-SI2.611598) (CO2StoP, 2013). This project conducted an initial assessment of the CO_2 storage capacity in Europe, including both onshore and offshore sites. The storage capacities are categorised into aquifers and hydrocarbon fields. Additionally, the CO2StoP project database was updated with more recent national storage estimates for Norway and Denmark. It is important to note that the CO2StoP database is not entirely up to date, and the storage capacities were not assessed for all locations. For example, storage locations and capacities for several countries were not assessed within the CO2StoP project due to various reasons such as restrictions related to availability of data owned by private companies (Lyng Anthonsen and Christensen, 2021). However, the CO2Stop dataset still represents the most detailed source of CO_2 storage data for this analysis (Figure 2). The analysis is based on storage unit (marked green on Figure 2) estimates and where they were not available, the daughter unit estimates (marked dark green) were used. Storage locations for which capacity assessments have not been conducted within the CO2StoP project were not considered in the analysis (marked red on Figure 2).The formation level was not used since the storage units and daughter units are the units of the storage potential assessment (Poulsen et al., 2014; Poulsen et al., 2014).

Figure 2. Overview of the CO2StoP project results and data used in the study



Source: JRC, 2024

The above-mentioned datasets provide a large number of possible CO_2 sources and sinks. However, as the storage locations obtained from the CO2StoP project are represented as polygons, a mathematical algorithm is employed to calculate the centroid of each polygon. This centroid is determined by calculating the average coordinates of all the points within the polygon. This process enables a simplified representation of the storage locations for further analysis and does not necessarily represent the location of a future storage project.

To handle the large number of possible sources and sinks, a mathematical clustering algorithm is utilised to group the locations into clusters. This clustering process helps to simplify the model and make it computationally manageable. What is more important, clusters need to be created because the CO_2 transport network is less likely to be developed on a project-by-project basis. By employing this approach, multiple projects can share the transport network.

Each cluster centre becomes a 'node' in the network, either a 'source node' or a 'sink node'. Each node represents a point location that does not necessarily refer to a specific CO_2 source (e.g. an existing power plant or energy-intensive industry facility) or sink (e.g. an aquifer or hydrocarbon field). The clustering is performed separately for sources and sinks, and the approach remains consistent regardless of the origin of the captured CO_2 (power generation or process-related CO_2 source) or the type of sink (saline aquifer with- or without hydrocarbon fields). The distinction between sinks is based on their onshore or offshore location.

Identification and clustering of the CO_2 sources and sinks are based on their geographical location and the weighted value of CO_2 captured capacity and total storage capacity, respectively, meaning that the node is created closer to the locations with higher capture and storage capacity. The clustering algorithm chooses the most suitable set of cluster centres applying an incremental approach from 2025 to 2050. Each year, clusters are determined by maintaining the clusters from the previous year and incorporating new locations that are either sources or sinks. The process involves assigning these new locations to existing clusters if within the radius of influence (below 100 km) or creating new clusters using the k-means algorithm, with a constraint of a maximum 100 km radius for new clusters.

This approach ensured a dynamic and adaptive clustering methodology for tracking and managing CO_2 capture and storage estimations over the time frame of the study and giving more weight to first chronologically appearing sites. The chosen approach, considering the announced CCS projects, entails the construction of the CO_2 transport infrastructure closer to the sites of CCS early adopters. These early adopters primarily consist of high-emitting entities that have taken the initiative in implementing CO_2 capture technologies. By focusing on these early adopters, the initial development of the CO_2 transport infrastructure can effectively support their efforts in reducing emissions.

Following the identification and clustering process, the total amount of CO_2 captured at each source node is calculated by summing the individual amounts of CO_2 captured across all sources within the corresponding source cluster. The same principle applies to the sink nodes, where the total storage capacity is determined by aggregating the injection capacities of all storage sites within the sink cluster. In order to prevent unrealistic fragmentation of CO_2 capture and storage sites, threshold values are applied. Source nodes with CO_2 capture totalling below 0.5 Mtpa and sink nodes with a total storage capacity below 25 Mt before 2035 and below 200 Mt after 2035 are excluded from the analysis. In case a source node is formed consisting of only one potential source location, the resulting node is excluded from the analysis if the capture capacity of that source node is less than 0.3 Mtpa. In addition, the injection capacities of the storage nodes with large total capacities were limited to 50 Mtpa. For CO_2 source nodes with a capacity lower than 0.5 Mtpa, it is assumed that the transportation of CO_2 to the main network will be facilitated through alternative modes such as trucks, rail, barges, or, in the case of smaller amounts of CO_2, captured on islands, via shipping.

The number of source nodes per country is related to announced projects and their capture capacities and to projected capture capacities. The same principle applies to the sink nodes.

2.1.2 Assumptions on the evolution of captured CO_2 emissions and storage capacities

In comparison with the original study, this analysis adopts two distinct approaches regarding the evolution of CO_2 capture and storage amounts: one for the period before 2035 and another for the period between 2035 and 2050. The approach for the period before 2035 relies solely on the available information regarding announced projects (Annex 1). It is important to note that the project list and the project information reflect the information publicly available at the time the project dataset was created (October 2023) and may change over time. On the other hand, the approach for the period after 2035 utilises projected data from energy and climate models for capture locations and updated CO2StoP project data for storage locations. By employing these different approaches, the analysis takes into account the evolving nature of the CO_2 transport network and incorporates both current and possible future developments.

The dataset containing announced projects was created internally within the JRC in October 2023 using a variety of data sources. These sources included publicly available CCS/U project databases, IF (Innovation Fund) list, 1st Union list of Projects of Common Interest (PCIs) and Projects of Mutual Interest (PMIs) under the revised TEN-E Regulation, as well as direct communications with project developers, relevant groups and stakeholders. The location, operation starting year, and CO_2 capacity of a project had to be known for it to be considered in the study. The capacities of some projects had to be estimated, considering that the capacity was available at the cluster level only.

The total amounts of CO_2 captured for 2040 and 2050 are taken from the results of the S3 scenario of the 2040 Climate Target Plan (CTP) modelling and from the modelling results of the full package scenario of the Fit-for-55 exercise. Both sources of data are based on the PRIMES model data.

The 2040 Climate Target Plan modelling results provide projections of the total amount of CO_2 emissions and CO_2 captured considering power generation, process-related activities and CO_2 removed from the atmosphere. In this analysis, projections of the amounts of CO_2 planned to be stored were used.

The Fit-for-55 modelling results provide projections of the total amount of CO_2 emissions and CO_2 captured per Member State considering both power generation and process-related activities. According to the Fit-for-55 exercise, no CO_2 capture is expected until 2040.

The main differences between the two scenarios mentioned are shown in Table 1. It shows the projections of captured CO_2 that need to be stored. Projected CO_2 capture values are coupled with the CO_2 capture amounts from the announced CO_2 capture projects. The Fit-for-55 modelling involves a slower increase of CO_2 capture compared to CTP 2040 modelling. The CTP 2040 modelling is characterised by a sharp increase in CO_2 capture until 2040, followed by stagnation.

Table 1. Projected CO_2 capture that needs to be stored (Mtpa)

Modelling	2030	2040	2050
CTP 2040	58.8	242.9	247.2
Fit-for-55	58.8	113.7	245.3

Source: JRC, 2024

To determine the geographic locations and quantities of captured CO_2 as accurately as possible, assumptions were made regarding the geographical distribution of CO_2 sources and the amount of CO_2 captured. The ETS registry dataset was compared to Eurostat's air emission inventory to determine the extent to which the ETS registry data reflects emission data. Ratios between these two datasets were calculated to determine the total emission values for each installation in 2040 and 2050. Consequently, the projected CO_2 capture for each country was allocated to installations with the highest emissions within that country, resulting in the creation of a dataset representing the CO_2 sources for 2040 and 2050. The locations of the CO_2 sources, i.e. source nodes, mostly remain consistent over time. However, as more facilities adopt capture technologies, new nodes may emerge, and existing ones may undergo slight location changes. This allows for a comprehensive representation of the evolving CO_2 capture landscape and facilitates the analysis of the CO_2 transport network development.

For each CO_2 source node, assumptions are made regarding the starting date of capture operations, the annual amount of CO_2 captured and its evolution over time. It is important to note that these assumptions are subject to uncertainties and may be refined as additional information becomes available or as circumstances change.

The locations and capacities of the potential CO_2 storage sites, i.e. sink nodes for 2040 and 2050, are derived from the CO2StoP project database updated with the more recent national storage estimates for Norway and Denmark. For each sink node, assumptions are made regarding the total storage capacity, the earliest possible starting date of storage operations, the maximum annual injection rate and its evolution over time (phased approach).

It is important to note that there is no complete data on the starting date of storage operation for each node and the starting date was assumed considering a sufficient development phase to ensure the establishment of storage infrastructure. The locations of CO_2 sink nodes remain consistent in both 2040 and 2050, meaning that the identified storage sites remain unchanged over time. For the period before 2035, announced starting dates of storage operations were used. A phased approach was used for both storage data sources. Project developer announcements were used for the announced projects for the period before 2035. Storage nodes from the CO2StoP project become active after 2035, taking into account the required development time. During the period from 2035 to 2040, a phased approach was used and after that, the maximum capacity per storage node was set to 50 Mtpa, considering the time needed and technical constraints in the development of storage nodes and taking into account the uncertainties and knowledge gaps of existing storage data.

Due to the lack of available data on the maximum annual injection rate and the fact that existing storage projects use only a fraction of the maximum injection capacity of their storage, a similar approach was adopted as in the original study. It is assumed that the injection process for CO_2 into a storage reservoir can be compared to the extraction of fluid from an oil reservoir in the oil sector. To estimate the maximum annual injection capacity for each storage node, the global reserves to production ratio (R/P) for oil at the end of 2020 was considered. The R/P ratio represents the number of years that the known reserves of a particular resource can sustain current production levels. For oil, the R/P ratio was 53.5 at the end of 2020. Based on this assumption, the maximum annual injection capacity for each CO_2 storage node is calculated as 1.87% of the total storage capacity. It is important to note that this approach provides a conservative estimate, as it assumes a similar utilisation rate as observed in the oil sector. While this assumption allows for an estimation of the maximum annual injection capacity, it is crucial to gather more specific data and conduct further research to refine these estimates and consider the unique characteristics of CO_2 storage operations. This assumption does not apply to the announced storage projects, where the maximum annual injection capacity was known.

In addition to the source and sink nodes, this analysis includes CO_2 terminal (hub) nodes. They represent locations where CO_2 is collected and can be further transported. Their locations are identified based on the announced CO_2 terminal projects. The specific starting dates of operations for terminals nodes are determined based on the requirements of the transport infrastructure.

This study uses eight different scenarios to analyse the implications of variations in input data and assumptions. Six scenarios use the latest Commission's modelling results of the S3 scenario within the 2040 Climate Target Plan (CTP), and two scenarios are based on the previous modelling results of the full package scenario for the Fit-for-55 (Ff55) exercise.

The first five CTP 2040 scenarios differ in their assumptions on potential storage locations. In CTP 2040 group A, three scenarios consider options for using CO_2 storage depending on whether the storage sites are located just in the EU (A1) or EU and Norway (A2) or EU, Norway and UK (A3). CTP 2040 group B assumes offshore storage capacities only (B1: EU only, B2: EU + Norway + UK). The last scenario, based on the CTP 2040 modelling results (NZIA), investigates the development of the CO_2 transport network by reflecting the annual storage capacity objective of 50 Mtpa in EU by 2030 as outlined in the Net-Zero Industry Act proposal (European Commission, 2023) and uses CTP 2040 data for 2030 and onwards.

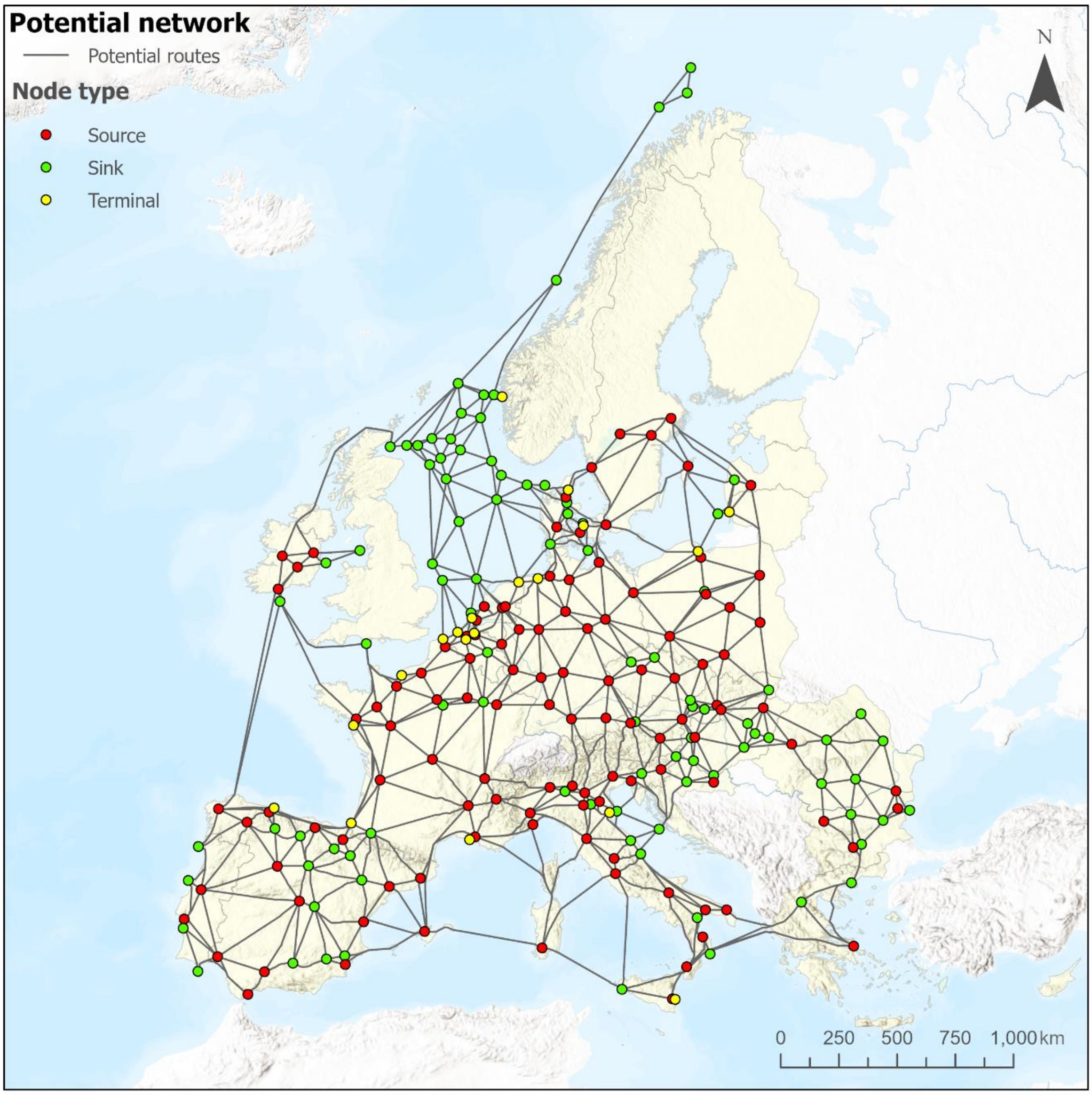
Based on the results for the Fit-for-55 exercise, two scenarios are developed. The first scenario (D1) investigates the possibility of CO_2 storage in the EU, Norway, and the UK and the second scenario analyses the development of the transport network based on the above mentioned NZIA storage target objective of 50 Mtpa in EU by 2030 (D2). Both scenarios take into account the projections of CO_2 captured based on the Fit-for-55 exercise.

Additional details about these scenarios are explained in Section 3.

2.1.3 Identification of potential routes between nodes

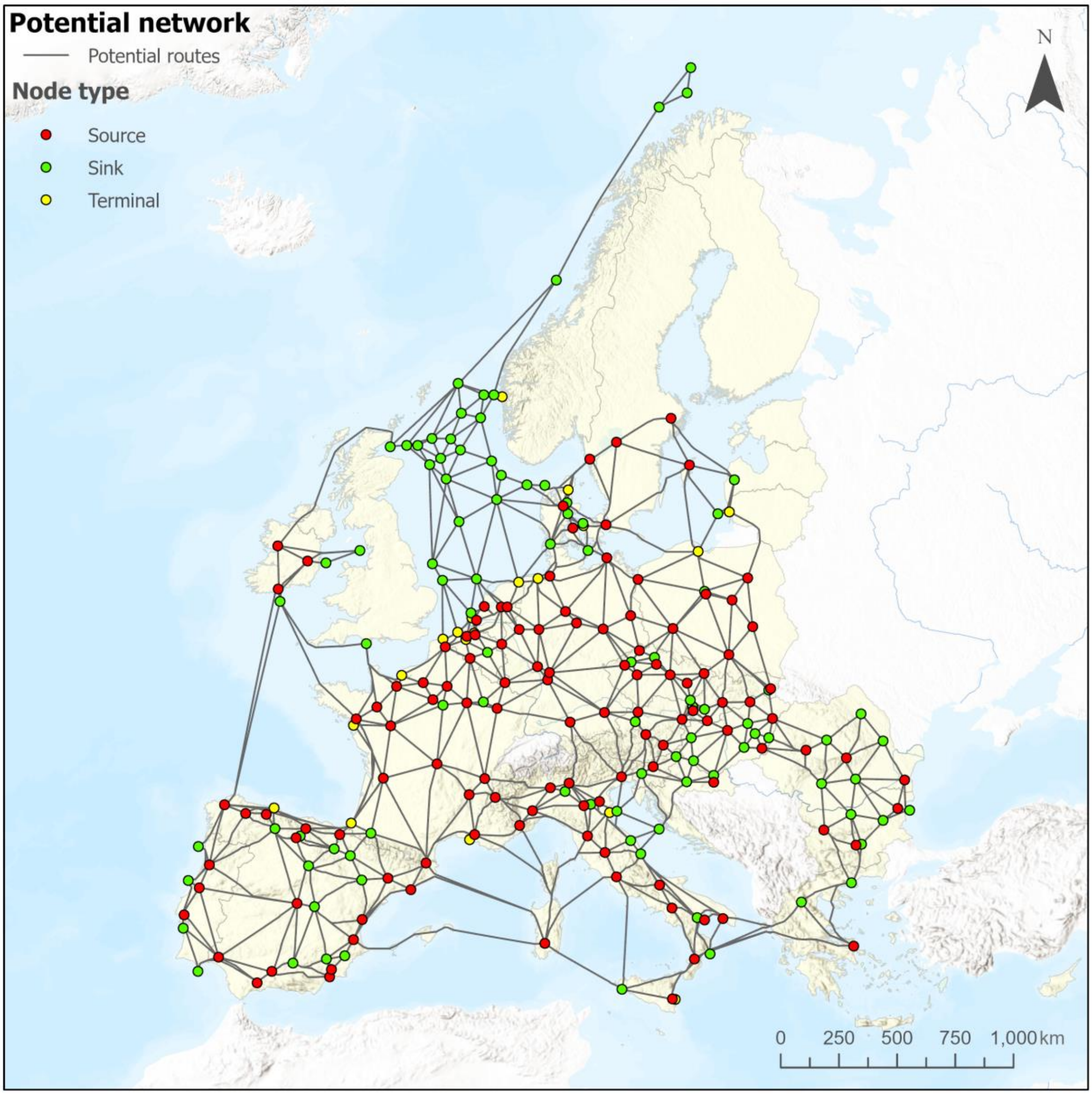
Once the source, sink and terminal nodes are identified and created, the potential route network between them is established using GIS-based tools. Consequently, each node is connected only to several of the neighbouring nodes within the study area. The routes are restricted to the area of the EU, and Norway and the UK in relation to storage sites (Figure 3 and Figure 4). The analysis included 114 (CTP 2040) or 120 (Fit-for-55) source nodes, 95 sink nodes, 19 terminal nodes and 603 (CTP 2040) or 624 (Fit-for 55) potential network connections with the total length of 113 398 km (CTP 2040) or 113 749 km (Fit-for-55).

Figure 3. Network of potential routes (CTP 2040)



Source: JRC, 2024

Figure 4. Network of potential routes (Fit-for-55)



Source: JRC, 2024

The routes can be established between two different types of nodes (source-sink, source-terminal, terminal-sink), and also between the nodes of the same type (source-source, sink-sink, terminal-terminal). This approach is based on the reasoning that captured CO_2 can be collected from several source nodes and then transported to terminals or sinks, or transferred between different sinks if it proves to be the cost-optimal solution.

The creation of the potential route network takes into consideration a cost surface raster dataset that incorporates terrain-related correction factors. These factors vary based on the type of surface and environment encountered. Different surface types and environments lead to varying costs for constructing routes. For instance, constructing a route through mountainous regions is more expensive compared to a route of the same length through lowlands. By using this approach, the potential route network consists of the cost-minimised routes between nodes. The terrain-related factors assigned are shown in Table 2.

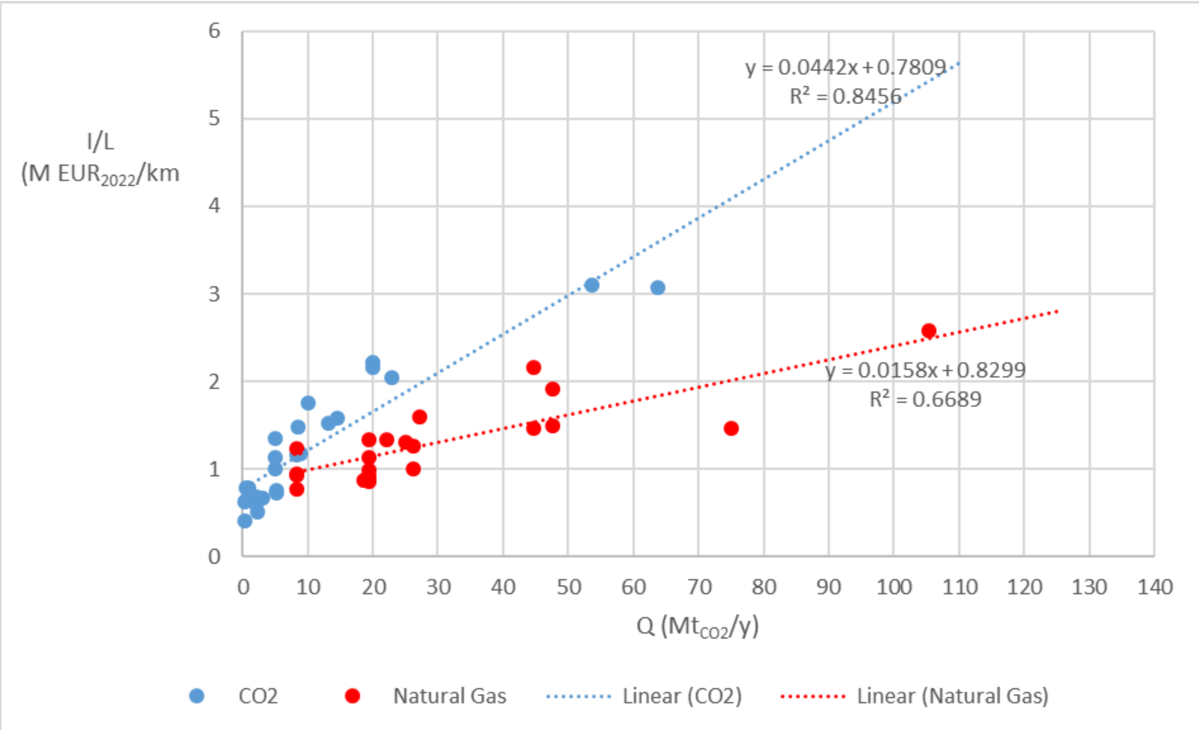
Table 2. Terrain-related cost factors assigned in this study

Area	Altitude	Cost factor
Onshore	< 1 000 m	1
Onshore	≥ 1 000 m – 2 000 m	1.25
Onshore	≥ 2 000 m – 3 000 m	1.5
Onshore	≥ 3 000 m	3
Offshore	n.a.	2

Source: JRC, 2024

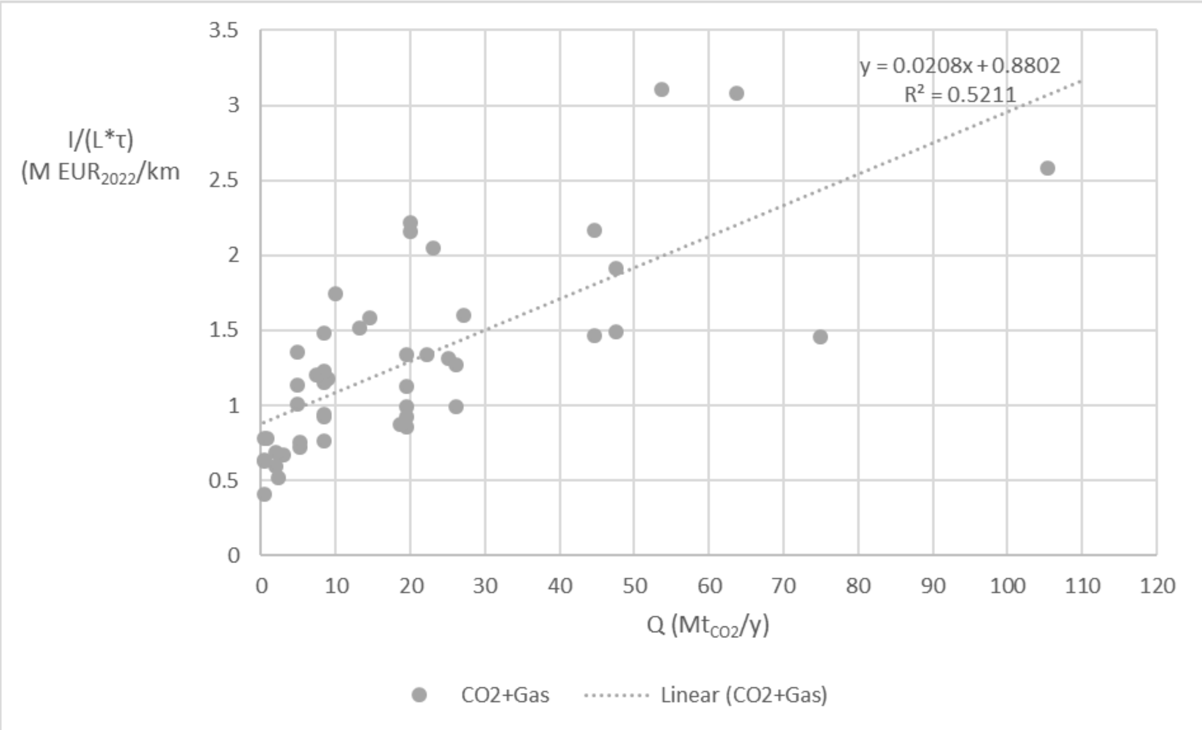
After the network of potential cost-minimised routes between nodes is established, the investment costs for each route are estimated. This estimation is based on the analysis of available cost estimates for CO_2 and natural gas existing and planned onshore pipelines (Serpa, Morbee, and Tzimas, 2011; Mikunda et al., 2011; ZEP, 2011; CCS Cost Reduction Taskforce, 2013; Knoppe, Ramirez, and Faaij, 2013; IEAGHG, 2014; National Energy Technology Laboratory (NETL), 2019; Element Energy, 2020; US National Petroleum Council, 2021; Smith et al., 2021; Zimmerman, Langenbrunner, and Aitken, 2022; Enhance Energy Inc., North West Redwater Partnership and Wolf Carbon Solutions Inc., 2022; Langenbrunner, Aitken, and Rozansky, 2023). The results of the onshore cost analysis are represented in Figure 5 and Figure 6. Integration of the cost analysis into cost-minimised route network results in a cost route network. It is important to note that, in comparison with the original study, the costs for pipelines with the same capacity and length are significantly higher.

Figure 5. Estimation of onshore pipeline transport costs (CO_2 – blue, Natural gas – red)



Source: JRC, 2024

Figure 6. Estimation of onshore pipeline transport costs – medium estimate



Source: JRC, 2024

The cost of each route is calculated by multiplying the average cost factor of the route by its length. This cost value is used in the network optimisation step of the analysis, which determines the optimal set of routes over times and their capacities (Mtpa). The final cost of each route is subsequently obtained by multiplying the cost of the route with its capacity. This approach does not require the use of multiple discrete pipeline diameters.

The pipeline investment costs are expressed in EUR_{2022} and the cost calculation considers economies of scale. A discount rate of 8% is assumed, as reported in the literature (ZEP, 2011; Bjerketvedt, V.S., A. Tomasgard, and S. Roussanaly, 2020).

The analysis does not provide a specific solution regarding the choice between offshore pipeline infrastructure and shipping for CO_2 transport. It assumes that the costs associated with offshore pipeline transport are equivalent to those of shipping. A more in-depth analysis of the costs of these two transport network types, including differences in operating costs, is beyond the scope of the present analysis and will be considered in future updates of this study.

2.1.4 Selection of the optimal network and evolution over time

The optimal deployment of a CO_2 network is achieved using an optimisation model which determines the optimal set of routes to transport given amounts of CO_2 captured from capture sources to the sinks, minimising the total net present value of CO_2 transport infrastructure investment costs.

To achieve the cost-optimal deployment, for each candidate route and at each point in time, the optimisation model decides whether to build the route and calculate its total capacity, as well as the flow rate, since it may not be fully utilised at all points in time. Furthermore, the model determines the optimal amount of CO_2 to be stored at each sink node, at each point in time.

The outcome of the process is an optimised network configuration that matches the CO_2 captured at the source nodes with the CO_2 stored at the sink nodes at each year from 2025 to 2050. This means that the network is designed to transport the captured CO_2 from the sources to the appropriate storage locations, ensuring that the overall CO_2 balance is maintained at each point in time, minimising the cost of the CO_2 transport network.

2.2 Important notes

- Given the broad spatial and temporal coverage of the analysis, the results should be considered as indicative and in the context of the assumptions made. They provide a first 'order of magnitude' estimate of the extent of the CO_2 network and the investment required as well as an insight into its international character. The results are subject to certain assumptions, which may introduce uncertainties and limitations. These assumptions are based on available data, models, and expert knowledge, but further refinement and validation are necessary as more accurate and up-to-date information becomes available.
- The analysis utilises data from the CO2StoP project and updated national CO_2 storage estimates. It is important to acknowledge that these datasets may vary in terms of the level of detail in their assessments. Consequently, there is a possibility of discrepancies in the storage potential data, which can impact the accuracy of the CO_2 transport network deployment. For the same reason, the CO_2 storage estimates on a more detailed level for specific locations, made as a part of several EU-funded projects, were not included in the analysis. In addition, the analysis does not go into a deeper consideration of the technical, economic, legal and social aspects of the utilisation of the CO_2 storage capacities beyond already considered within the CO2StoP project.
- The nodes on the map may represent specific projects, particularly in the case of terminals and CCS projects for the period until 2035. However, it is important to note that, in general, the nodes on the maps should not be associated with specific CO_2 source, sink or terminal projects.
- The analysis approach is from the CO_2 capture side. It means that in all of the considered scenarios, the CO_2 captured at any point in time needs to be stored at that point in time. To achieve that, available CO_2 storage capacity has to be higher or equal to CO_2 capture capacity.
- The optimisation model takes into account the whole period of the optimisation until 2050. If the node is not active at that point in time but will become active later, the optimisation model can decide to build a route to that node before the node becomes active if the route is used to transport the CO_2 between other nodes and if that is a cost-optimised solution. In addition, the model can build the route earlier in order to accommodate additional CO_2 volumes anticipated in the following years if that is a cost-optimised solution.
- The analysis assumes that the CO_2 captured within the announced projects will need to use the CO_2 transport network, even though it is sometimes not the case (e.g. CO_2 captured for utilisation). This approach ensures that there is enough space in the main CO_2 transport network for CO_2 coming from various sources not considered in the analysis, such as small capture sites or new installations not covered by the ETS registries e.g. Direct Air Capture (DAC) and Bioenergy with Carbon Capture and Storage (BECCS).
- Due to the significant variation in cost estimates for CO_2 onshore pipelines, it is important to acknowledge that the actual costs may differ from the results obtained in this analysis. Additionally, the investment cost analysis does not account for the cost differences caused by varying pipeline pressures.

- The analysis does not consider CO_2 specifications for maximum impurity concentrations and potential effect on the CO_2 transport infrastructure, as common EU standards covering these aspects do not exist.
- The analysis does not differentiate between offshore pipeline infrastructure and shipping for CO_2 transport. It assumes that the costs associated with offshore pipeline transport are equivalent to those of shipping (Table 2). The analysis of the costs of these two transport network types is beyond the scope of the present analysis and might be considered in future updates of this study.
- The analysis is based on the latest available data (October 2023) on the CCS infrastructure for the area of Europe and uses the most advanced and appropriate software tools.

3 Scenarios

Given the uncertainties and varying perspectives surrounding the evolution of CO_2 transport infrastructure in Europe, the analysis acknowledges the need for multiple scenarios to explore different potential outcomes. By running several scenarios, the analysis can provide a comprehensive understanding of the potential pathways and implications of different CO_2 transport infrastructure developments in Europe. This approach allows for a more robust assessment and consideration of the range of possible future scenarios in the early phase of CO_2 transport network development. The main division of scenarios is based on two different Commission models: CTP 2040 and Fit-for-55.

3.1 CTP 2040 scenarios

3.1.1 Storage availability group (A1, A2 and A3)

The Storage availability group of scenarios (Group A) is based on the total capture capacities of announced projects in the EU before 2035 and projected capture capacities for the period after 2035. The announced CO_2 capture capacity in the EU, based on the applied methodology described in Section 2, amounts to 58.8 Mtpa. This value is higher than the EU objective of reaching an annual storage capacity of 50 Mtpa by 2030 as outlined in the Net-Zero Industry Act proposal (European Commission, 2023). It is important to note that this objective does not include potential storage locations in Norway and the UK.

Norway has been at the forefront of carbon storage and has made substantial progress in the development of carbon storage projects. In addition to well-established projects like Sleipner, Snøhvit, and the Northern Lights, several exploration licenses for storage operations have been awarded to different consortia. These projects demonstrate Norway's commitment to advancing carbon storage technology and infrastructure. Furthermore, Norway has developed a CO_2 storage atlas that provides valuable information about the significant storage potential on the Norwegian Continental Shelf. This atlas showcases over 80 Gt of storage potential in Norway (Norwegian Petroleum Directorate, 2019).

Following the UK's withdrawal from the EU, uncertainties have arisen regarding the potential for storing CO_2 captured in the EU in UK storage sites. The UK is estimated to have a storage potential of approximately 78 Gt (Pale Blue Dot, 2016). This significant storage potential, coupled with the proximity to the EU, could play a significant role in shaping the deployment of the CO_2 transport infrastructure network. However, the specific agreements between the EU and the UK regarding cross-border CO_2 storage and transportation are subject to negotiation, and uncertainties remain regarding future collaboration in this area.

In Group A, three different scenarios (A1, A2 and A3) are considered, each with its own set of assumptions and considerations regarding the use of storage sites for CO_2 captured in the EU.

- *A1 - CTP 2040 (EU)* is based on the total capture capacity of announced CCS projects within the EU before 2035. It does not foresee the use of storage sites outside the EU for CO_2 captured in the EU.
- *A2 - CTP 2040 (EU+NO)*, assumes the same capture capacities as A2. However, it considers the possibility of using storage sites in Norway, in line with the potential timeline of incorporating NZIA into the EEA agreement.
- *A3 - CTP 2040 (EU+NO+UK)*, like A1 and A2, is based on the total capture capacity of announced CCS projects before 2035 within the EU. In addition to storage capacity in the EU and Norway, it also includes the availability of UK storage sites.

It is important to note that the analysis considers the use of CO_2 storage sites outside the EU only when it represents a cost-minimising solution. The decision to utilise storage sites outside the EU aims to optimise the overall costs associated with CO_2 transport network.

3.1.2 Offshore storage group (B1 and B2)

In the Offshore storage group of scenarios (Group B), the assumption is that captured CO_2 can only be stored in offshore locations. The scenario assumes that onshore storage of CO_2 will be more complex to realise due to public concerns and legislative factors, even in landlocked countries.

Based on the identification and clustering exercise, the onshore storage nodes' capacity accounts for 43% of the total storage capacity. This indicates that a substantial amount of CO_2 can be stored at onshore locations, highlighting the potential and suitability of these sites for long-term storage of captured CO_2. The allocation of nearly half of the total storage capacity to onshore storage nodes underscores their possible importance and viability in the CO_2 storage infrastructure. Onshore storage provides advantages such as easier access and potential proximity to capture sources, which can contribute to cost-effectiveness of the CO_2 transport.

We have considered the following two scenarios under group B.

- *B1 - CTP 2040 & Offshore only (EU)* assumes that the CO_2 captured in the EU can be stored only in offshore storage locations and only in EU storage locations (without the UK and Norway).
- *B2 - CTP 2040 & Offshore only (EU+NO+UK)*, similar to B1, assumes that the CO_2 captured in the EU can be stored only in offshore storage locations. Contrary to B1 though, it also includes storage locations in the UK and Norway.

3.1.3 Scenario C1 - CTP 2040 & NZIA 2030 targets (EU)

The previous scenarios were based on the total capture capacities of announced projects in the EU before 2035 and projected capture capacities for the period from 2035 until 2050. The *C1 - CTP 2040 & NZIA 2030 targets (EU)* scenario takes a different approach, investigating the development of the CO_2 transport network by reflecting the storage capacity objective of 50 Mtpa in the EU by 2030 as proposed by the Net-Zero Industry Act proposal (European Commission, 2023) and uses CTP 2040 data for the time period 2030-2050.

3.2 Fit-for-55 scenarios

3.2.1 Scenario D1 - Fit-for-55 (EU+NO+UK)

Scenario *D1 - Fit-for-55 (EU+NO+UK)* is similar to *Scenario A3 - CTP 2040 (EU+NO+UK)*. It is based on the total capture capacity of announced CCS projects before 2035 within the EU as in scenario A3. CO_2 capture projections for the period after 2035 up to 2050 are based on the Fit-for-55 modelling results. In addition to EU storage capacity, it also includes the availability of Norwegian and UK storage sites.

3.2.2 Scenario D2 - Fit-for-55 & NZIA 2030 targets (EU)

Scenario *D2 - Fit-for-55 & NZIA 2030 targets (EU)* uses the same assumptions as Scenario *C1 - CTP 2040 & NZIA 2030 targets (EU)*. It explores the development of the CO_2 infrastructure network in the EU by reflecting the storage capacity objective of 50 Mtpa in the EU by 2030, as proposed in the Net-

Zero Industry Act (European Commission, 2023). The only difference is that the CO_2 projections for the period between 2035 and 2050 are based on the Fit-for-55 modelling results.

4 Results

In this section, the outcomes are presented of applying the methodology to each of the scenarios. The results of the optimisation are presented graphically, showing a time snapshot or the status of the CO_2 transport network in 2030, 2040 and 2050. The direction of CO_2 transport is marked by arrows. Each figure is accompanied by a brief description, and at the end of each scenario, there is a graphical representation of the distribution of the network length, by country, for each of the snapshots.

4.1 Scenario A1 - CTP 2040 (EU)

Before delving into the details of A1 results, it is important to note that based on the assumptions and data used, there is insufficient storage capacity in the years 2025 (1.31 Mtpa), 2026 (10.44 Mtpa), 2027 (12 Mtpa), 2028 (7.75 Mtpa), and 2029 (12.89 Mtpa) (Table 3). Since the analysis approach is from the CO_2 storage side, to solve the optimisation problem, the capture capacities had to be decreased for these specific years. That means that the start of operation for certain announced capture projects and their capture capacity development plans had to be postponed by several years. Without that, it would be impossible to solve the optimisation model, since one of the optimisation criteria is that all the CO_2 captured at a point in time also needs to be stored at that point in time. The captured projects were selected based on their distance to storage locations, planned capture capacities and secured funding to minimise investment costs. By implementing this approach, the available storage capacity is maximally utilised.

Table 3. Scenario A1 – gap in the storage availability

Year	2025	2026	2027	2028	2029	2030	2031
CO_2 captured (Mtpa)	1.86	12.59	25.35	38.20	48.02	58.83	69.83
CO_2 storage capacity (Mtpa)	0.55	2.15	12.35	31.45	35.13	65.83	71.33
CO_2 storage capacity gap (Mtpa)	-1.31	-10.44	-12.00	-7.75	-12.89	7.00	1.50

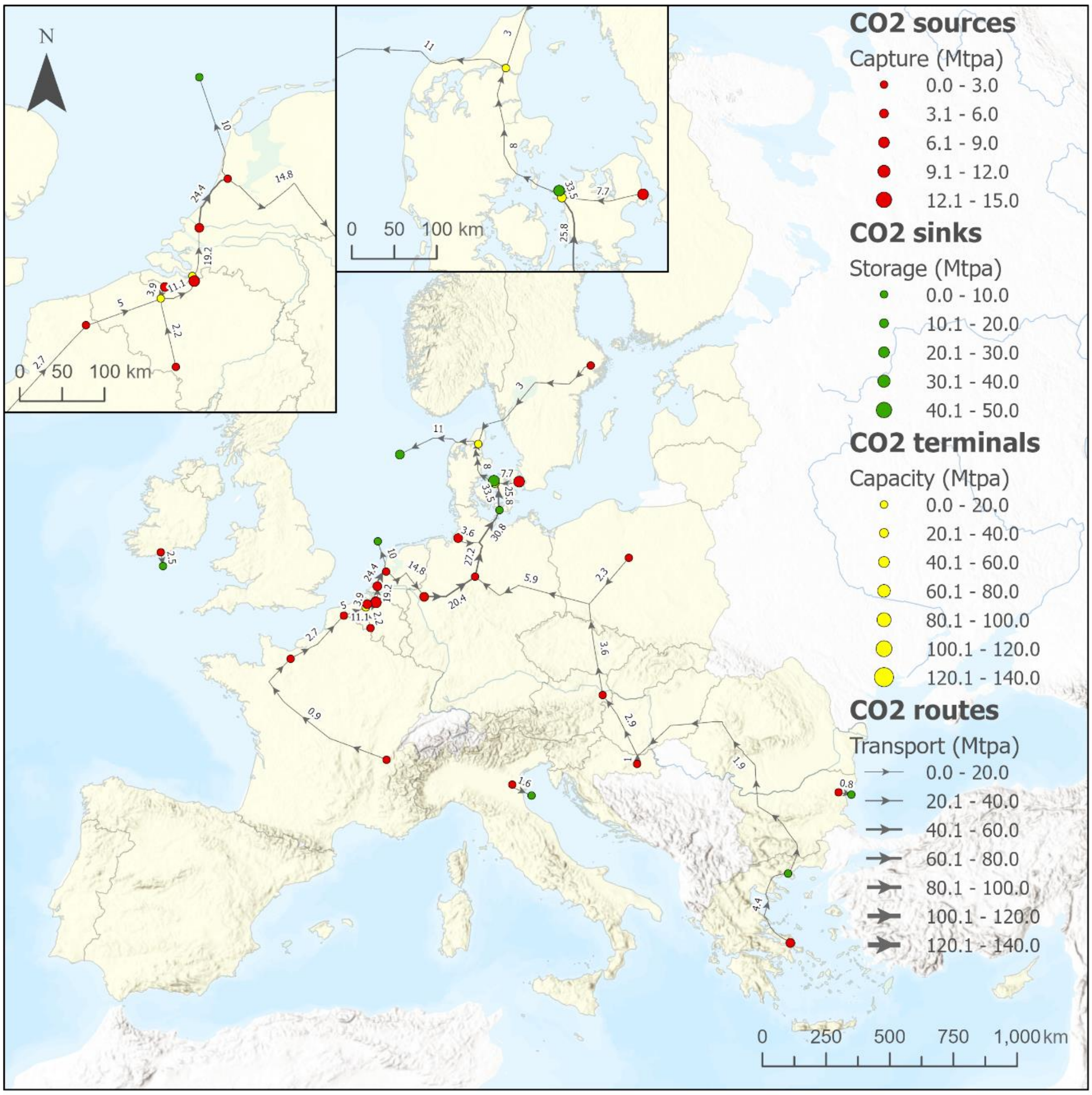
Source: JRC, 2024

The development of the European CO_2 transport network starts in the border area of Belgium and the Netherlands, and in Denmark, based on the capture and storage projects announced in those countries.

By 2030, the total capture, transport and storage capacity increases to 58.8 Mtpa. This is based on the significant increase of announced capture projects. Most of these storage projects are situated in the North Sea region, but there are also capture projects active in Greece, Bulgaria, Croatia, Austria, Italy and southern France.

Due to insufficient storage capacities in central and southern Europe, long segments of the network with relatively low transport capacities are being developed. They transport CO_2 from remote sources to active storage locations in the North Sea region and already anticipate CO_2 transport in later years through those pipelines. Notable storage locations are situated in the northern Adriatic, Greece and the Black Sea. The CO_2 transport network extends to 16 countries and the total length amounts to about 6 700 km (6 000 km onshore and 700 km offshore).

Figure 7. Scenario A1 - CTP 2040 (EU), year 2030



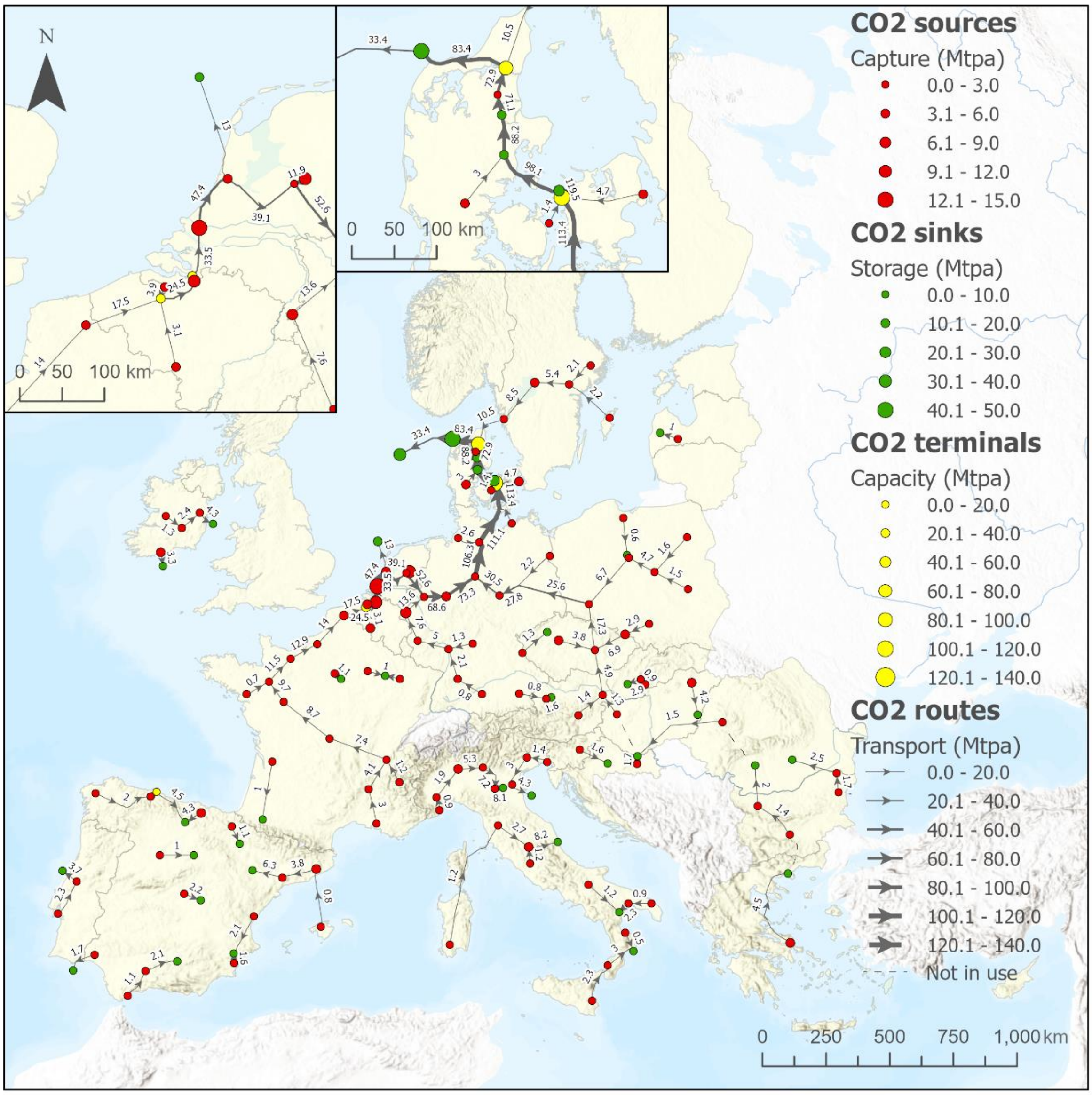
Source: JRC, 2024

Between 2030 and 2040, storage locations identified within the CO2StoP project, which were previously not used within the announced storage projects, become available for CO_2 storage. In this period there is a sharp increase in the implementation of the CO_2 capture technologies (21 countries with 111 active storage nodes) and the total CO_2 capture capacity increases to about 243 Mtpa. The total built CO_2 transport network increases to about 15 400 km but the used part of the network amounts to 14 800 km. This is because storage locations closer to capture locations become available and CO_2 is now being transported to the closer locations.

The parts of the transport network that are not used at the moment are represented by dashed lines on the maps and these parts are mostly related to the network built in previous period to transport CO_2 from remote sources to the active storage locations due to general unavailability of the storage capacity.

The CO_2 transport network evolves throughout the EU. There is one large network connecting central and western Europe and the North Sea region. Other transport networks are relatively smaller and mostly connecting capture and storage nodes between two countries or nodes within one country. The longest parts of the network are developed in Italy, France, Germany, Spain and Poland.

Figure 8. Scenario A1 - CTP 2040 (EU), year 2040



Source: JRC, 2024

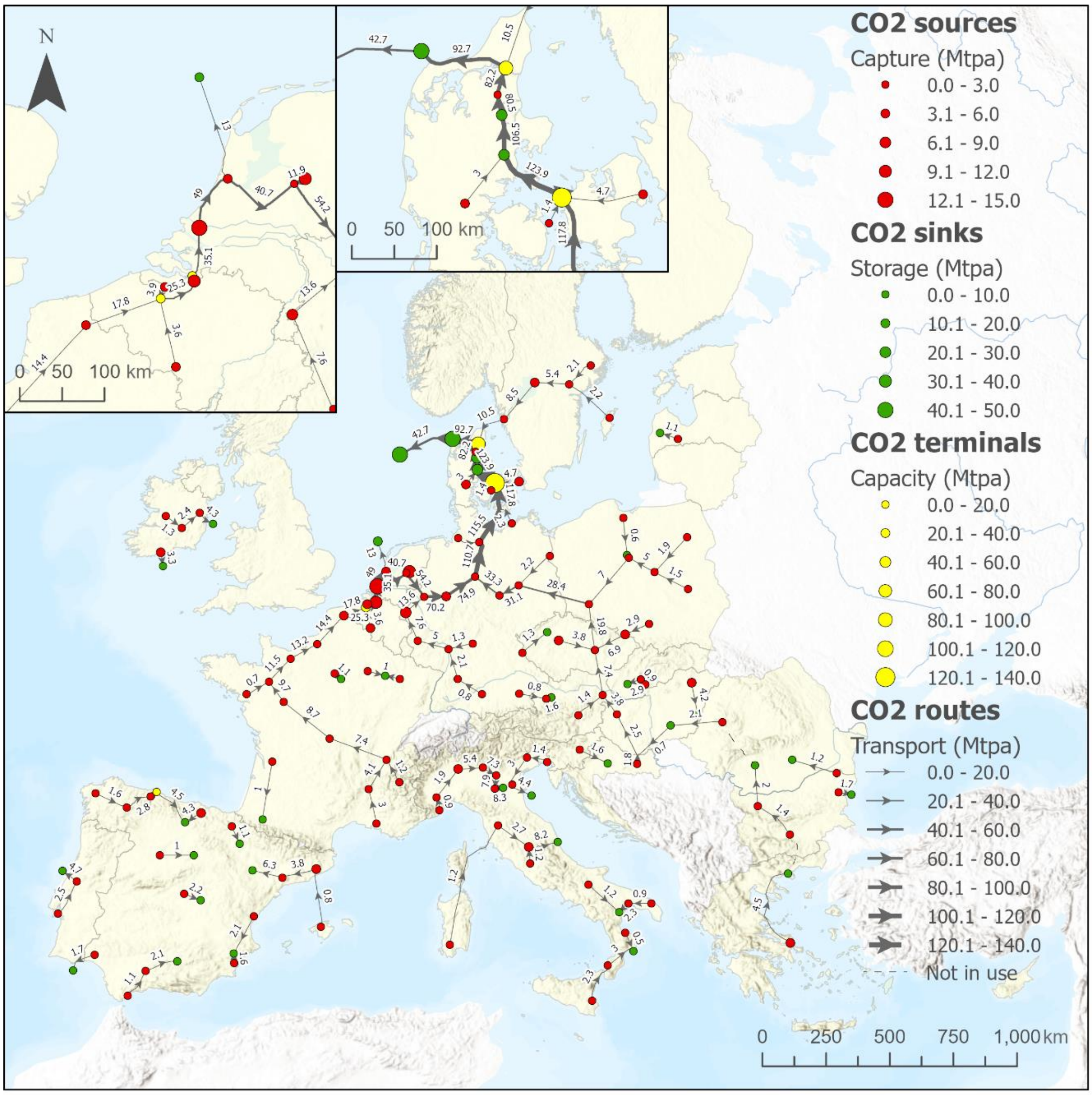
In 2050, the CO_2 transport network extends throughout 21 EU countries. About 250 Mtpa of CO_2 is being captured in 114 active capture nodes, transported via a network of about 15 000 km with 22 cross-border connections and stored in 36 active storage nodes.

The transport of relatively small amounts of CO_2 is developed from several island nodes to the mainland (e.g. 1.2 Mtpa from Sardinia and 0.8 Mtpa from the Balearic Islands). Instead of building a pipeline infrastructure for the transport of the CO_2, it is also an option to use shipping. However, as explained in the methodology, the analysis does not provide a specific solution regarding the choice between offshore pipeline and shipping.

There are parts of the network not used for the CO_2 transport anymore. They were built in the early phase of network development when few storage locations were available, but they became unnecessary when more storage nodes with enough storage capacity became available.

To avoid additional costs and construction of parts of the network infrastructure that will not be used for a longer period, one option could be to use alternative transportation methods, e.g. shipping, truck, rail and barge. The possibility is also to use this route to transport potential additional amounts of captured CO_2 that have not been considered by this analysis (small capture sites or new installations not covered by the ETS registries, e.g. DAC, BECCS). Other options involve postponing the CO_2 capture or choosing other means of decarbonisation, if feasible. To avoid such situations, better collaboration is needed among project developers and at pan-European level.

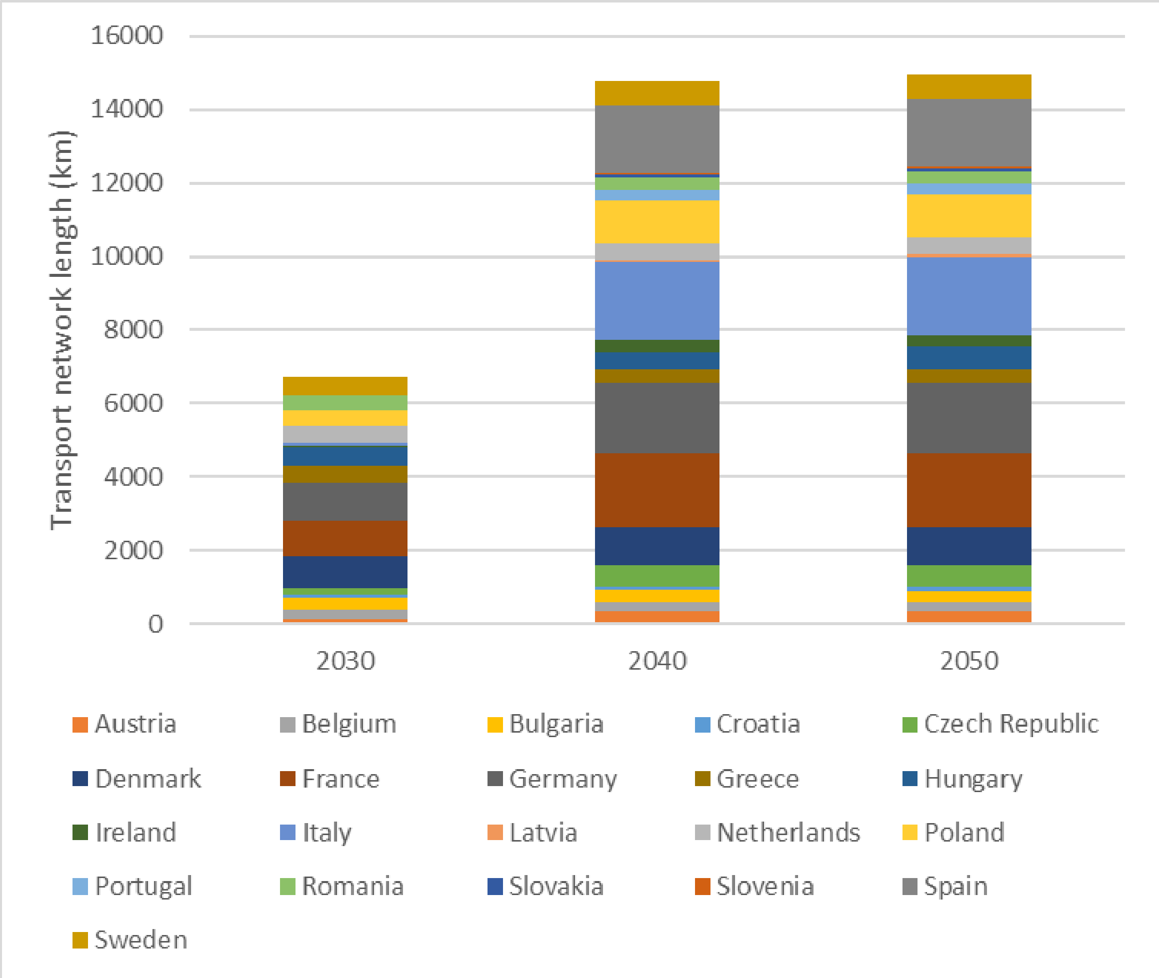
Figure 9. Scenario A1 - CTP 2040 (EU), year 2050



Source: JRC, 2024

Figure 10 shows the distribution of the length of the transport network used per country during the observed period.

Figure 10. Transport network length per country, scenario A1 - CTP 2040 (EU)



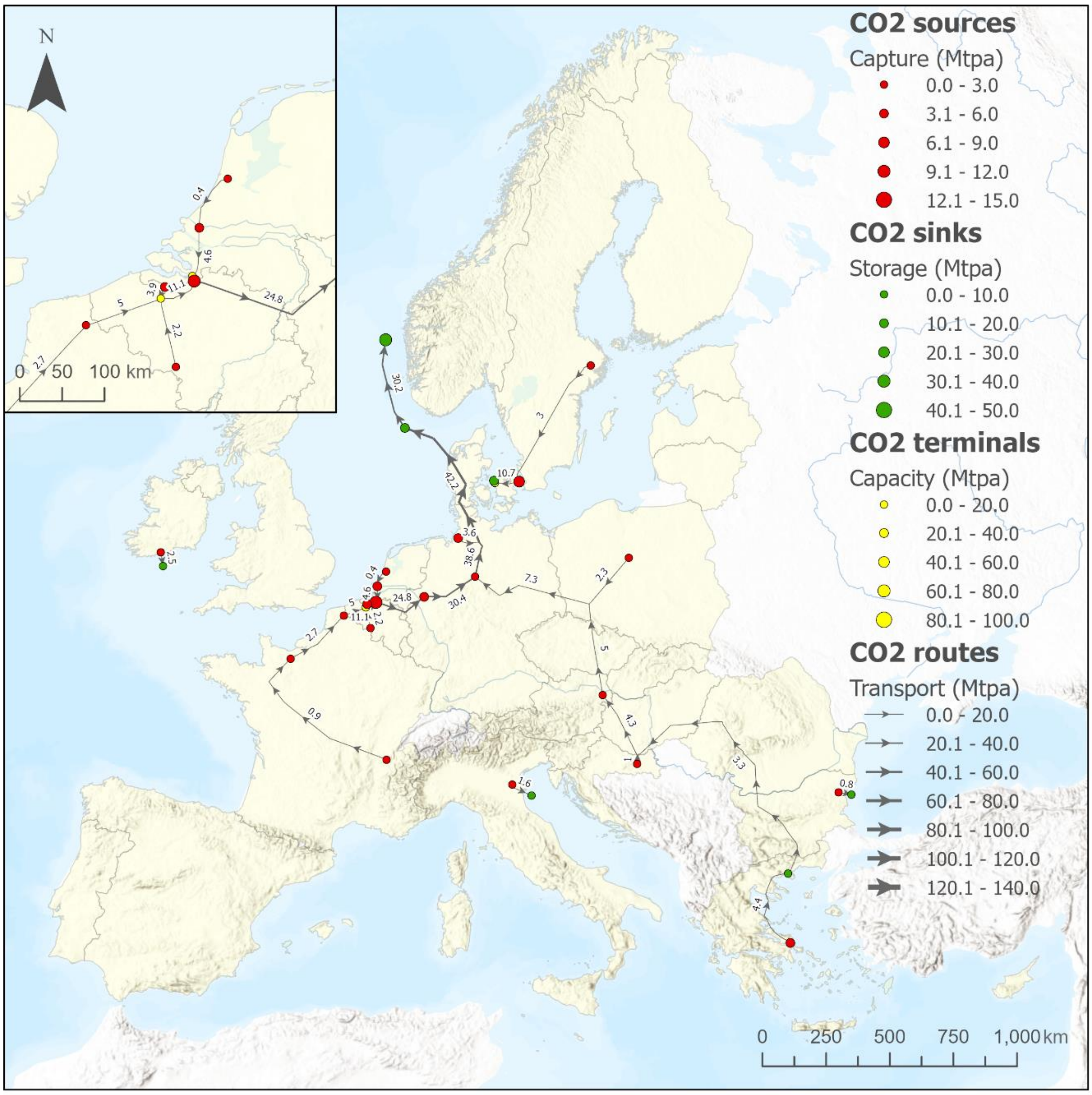
Source: JRC, 2024

4.2 Scenario A2 - CTP 2040 (EU+NO)

Scenario A2 assumes it will be possible to store the CO_2 captured in the EU within the EU and Norway. Compared to the Scenario A1, there is sufficient storage capacity during the early phase of the CO_2 transport network development, thanks to Norwegian storage capacities.

The development of the CO_2 transport network is very similar to the development in the previous scenario. The key difference is the availability of Norwegian storage capacity, which allows for the storage of all CO_2 captured during that period. As in the previous scenario, in 2030, a major part of the network is developed in the North Sea region. Also, a long route is being developed, connecting the CO_2 sources in Greece to the storage locations in the North Sea, since there are no active storage locations with sufficient storage capacity closer to the sources. This long route also collects and transports CO_2 captured in Croatia, Austria and Poland. In addition, the optimisation develops a route transporting relatively small amounts of CO_2 captured in south-eastern France to the North Sea region.

Figure 11. Scenario A2 - CTP 2040 (EU+NO), year 2030

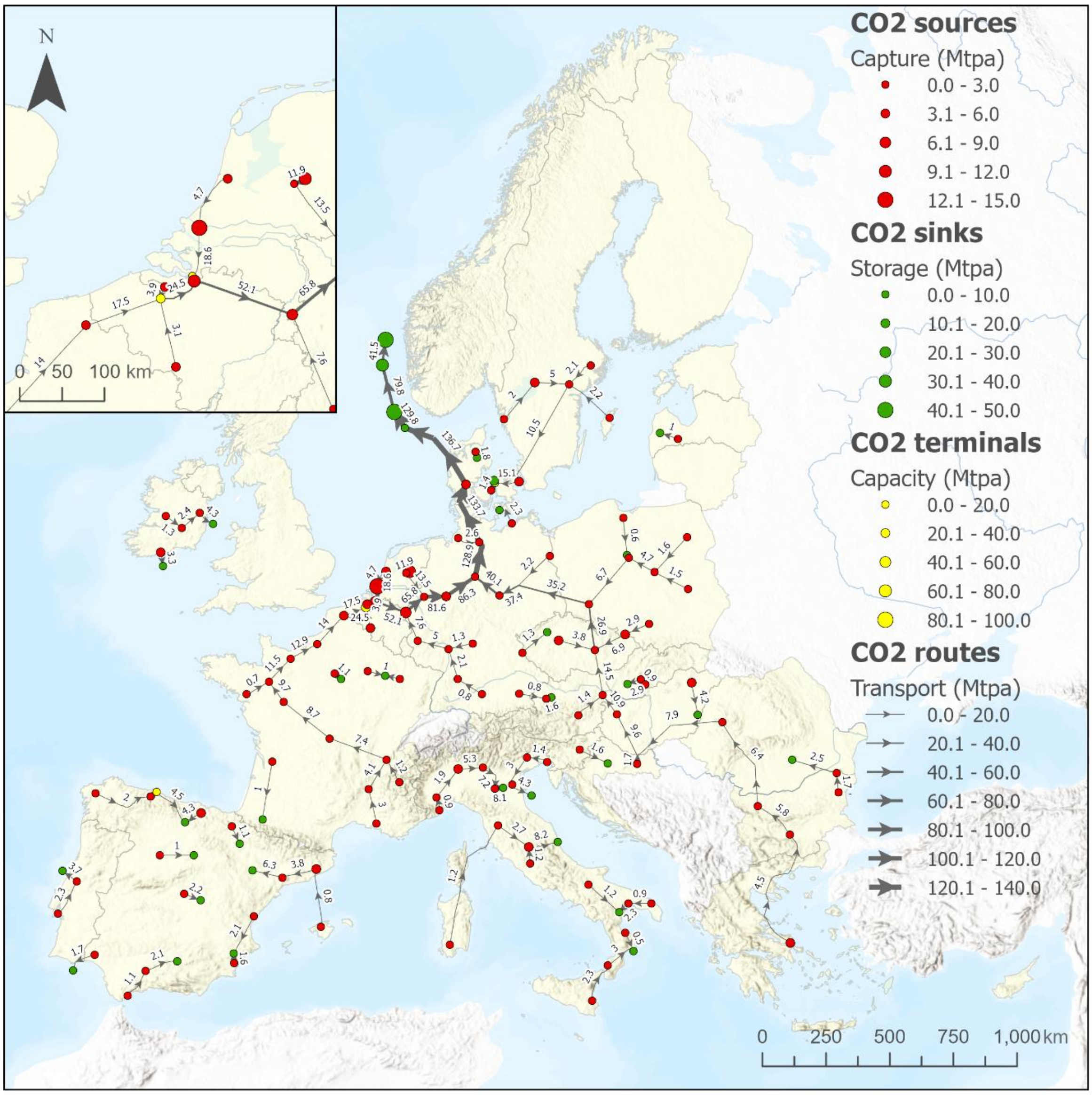


Source: JRC, 2024

The CO_2 transport network extends to 17 countries and the total length amounts to about 6 700 km (5 900 km onshore and 800 km offshore). Besides being most developed in Germany and France, the network has significantly expanded in Sweden, Hungary, Norway and Denmark.

By 2040, the capture capacity increases to about 243 Mtpa and the number of storage locations is highly increased due to the storage demand. The CO_2 transport is active in 22 countries and the transport network extends to 15 800 km. The development of the CO_2 transport network is almost identical to the development in the previous scenario. The main difference is in the North Sea region. Instead of greater use of storage capacities in the Netherlands and Denmark, CO_2 storage is transported and stored in Norway.

Figure 12. Scenario A2 - CTP 2040 (EU+NO), year 2040



Source: JRC, 2024

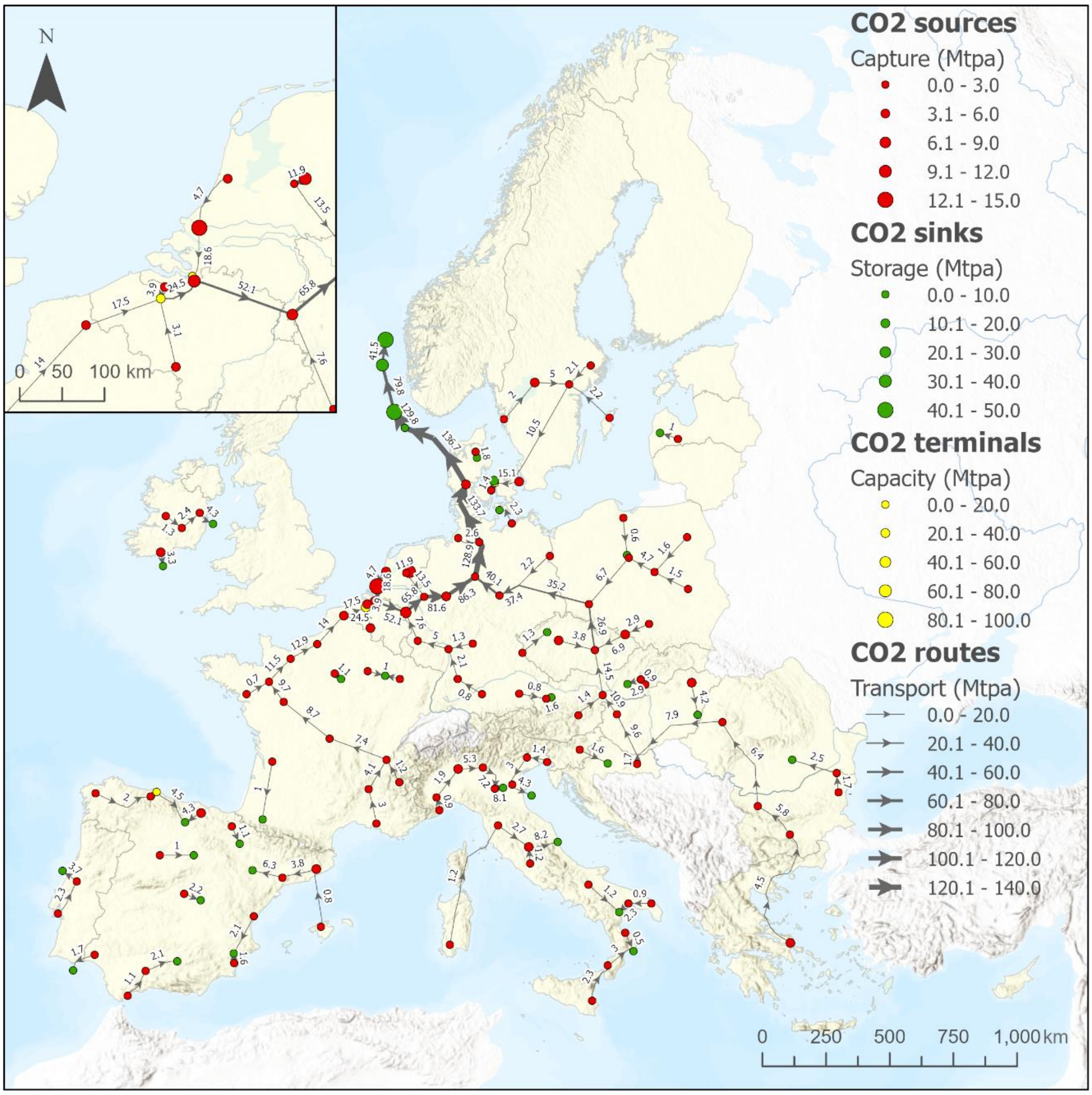
The total capture capacity in 2050 is slightly increased from 243 Mtpa to 247 Mtpa. The total length of the CO_2 transport network is the same as in the previous period, with a small increase of CO_2 flow in several routes. CO_2 is being captured in 21 countries and stored in 16. There are 23 cross-border connections.

There is a high-capacity route in northern Germany transporting almost half of the CO_2 captured in the EU to the storage sites in the Norwegian part of the North Sea. The remaining amounts of CO_2 are stored either within smaller interconnections (e.g. Spain-Portugal, Romania-Bulgaria, Slovenia-Croatia) or within smaller networks and connections developed within the countries (e.g. Italy, Spain, France, Portugal). The longest parts of the transport network are developed in Italy, France, Spain, Germany and Poland (Figure 14).

The transport of CO_2 is developed from several island nodes to the mainland. Instead of building a pipeline infrastructure for the transport of relatively small amounts of CO_2 (e.g. 1.2 Mtpa from

Sardinia and 0.8 Mtpa from the Balearic Islands), it is also an option to use shipping. However, the analysis does not provide a specific solution regarding the choice between offshore pipeline and shipping. Other options involve finding local storage solutions or other means of decarbonisation, if feasible.

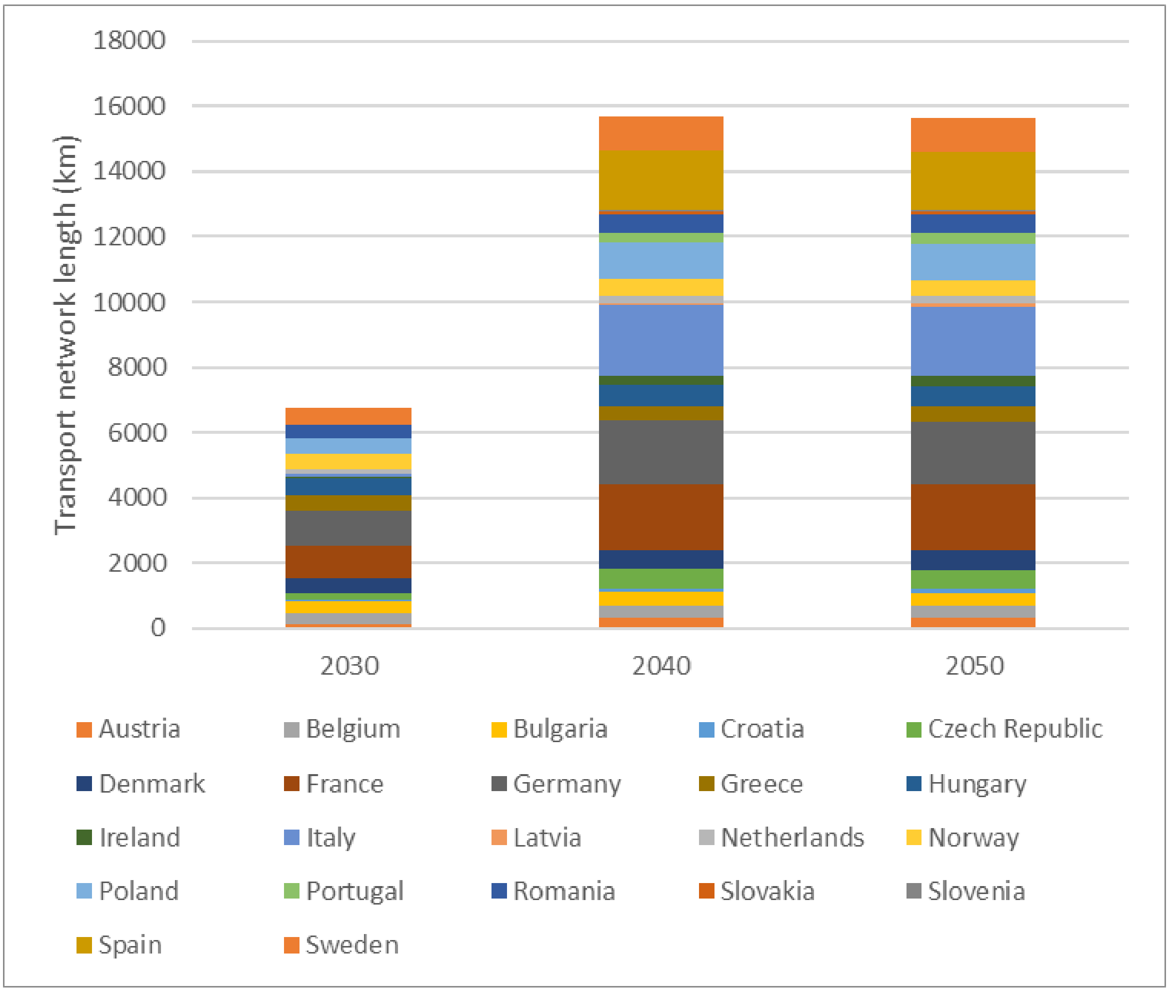
Figure 13. Scenario A2 - CTP 2040 (EU+NO), year 2050



Source: JRC, 2024

Figure 14 shows the distribution of the length of the transport network used per country during the observed period.

Figure 14. Transport network length per country, scenario A2 - CTP 2040 (EU+NO)



Source: JRC, 2024

4.3 Scenario A3 - CTP 2040 (EU+NO+UK)

In addition to the first two scenarios, Scenario A3 assumes it will be possible to store CO_2 also in the UK. The captured CO_2 is transported to the same offshore locations in Norway as in Scenario 2, with the difference that the optimisation model takes into the account the storage locations in the UK which become active only after 2035. The analysis considers the availability of storage locations in the UK, as well as the time necessary to address the legal requirements and barriers for storing CO_2 captured in EU in the UK storage locations.

The optimisation of Scenario A3 resulted in identical results as in Scenario A2. The CO_2 transport network is developing in the same way as in Scenario A2, using the same sink nodes and routes. This is happening because storage locations in the UK are only available after 2035 when a significant portion of the transport network is already formed and directed towards the Norwegian part of the North Sea. Constructing additional routes to storage locations in the UK would require additional investment, and the entire transport network would not be cost-optimised anymore. Results in this scenario could differ from A2 if storage locations in the UK become available earlier than assumed.

4.4 Scenario B1 - CTP 2040 & Offshore only (EU)

Scenarios B1 and B2 assume that the CO_2 captured in the EU can be stored only in offshore storage locations due to various reasons, such as a lack of public acceptance of onshore storage. The main difference is that scenario B1 assumes that CO_2 can be stored only in the EU, while scenario B2 also includes storage locations in Norway and the UK.

The assumption that the CO_2 captured can be stored only in storage locations inside the EU results in optimisation model problems similar to those in Scenario A1, where there was insufficient storage capacity in the years 2025 (1.31 Mtpa), 2026 (10.44 Mtpa), 2027 (12 Mtpa), 2028 (7.75 Mtpa) and 2029 (12.89 Mtpa). However, in this scenario, the problems with insufficient storage capacity become even more significant. Based on the data used, there is insufficient storage capacity in the years between 2025 and 2035 (Table 4). Storage capacity becomes sufficient only after all potential storage locations and capacities identified within the CO2StoP project become available. To solve the resulting optimisation problem, the same approach as described in Scenario A1 was used. The capture capacities had to be decreased and the entry into operation of certain announced capture projects and their capture capacity development plans had to be advanced by several years. The captured projects were selected based on their distance to storage locations, planned captured capacities and secured funding to minimise investment costs. By implementing this approach, the available storage capacity is maximally utilised.

Table 4. Scenario B1 – gap in the storage availability

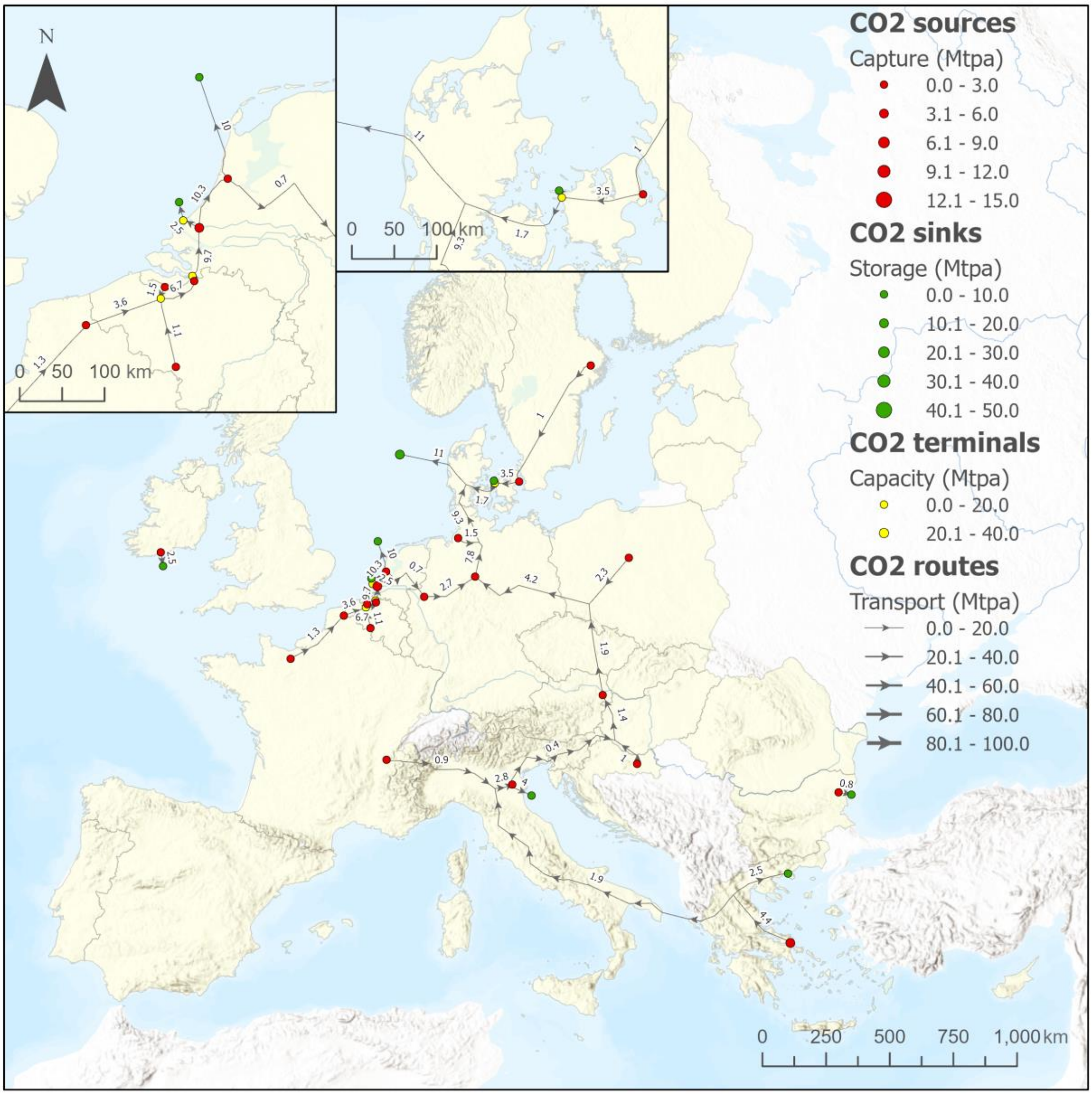
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
CO_2 captured (Mtpa)	1.86	12.59	25.35	38.20	48.02	58.83	69.83	71.92	80.63	89.34	98.04
CO_2 storage capacity (Mtpa)	0.00	4.10	9.50	26.6	30.28	33.28	33.28	33.20	33.28	33.28	33.28
CO_2 storage capacity gap (Mtpa)	-1.86	-8.49	-15.85	-11.60	-17.74	-25.55	-36.55	-38.72	-47.35	-56.06	-64.76

Source: JRC, 2024

As a consequence of insufficient storage capacity, CO_2 transport started in 2026 instead of 2025. In 2030, the CO_2 transport network consists of one large network which connects all the nodes except two source-sink pairs in Ireland and Bulgaria. Compared to previous scenarios, the CO_2 transport from southern Europe is routed through Italy. The excess of CO_2 from Greece is transported across the Adriatic Sea. Additionally, CO_2 captured in south-eastern France is also connected in Italy to the main network. Due to the inability to store CO_2 outside the EU and possibility to store it only offshore, the CO_2 storage nodes in the Netherlands, Denmark, Ireland, Italy, Greece and Bulgaria are used.

The CO_2 transport network extends to 17 countries and the total network length amounts to about 7 300 km (6 700 km onshore and 600 km offshore). There are eight active storage nodes in six countries.

Figure 15. Scenario B1 - CTP 2040 & Offshore only (EU), year 2030

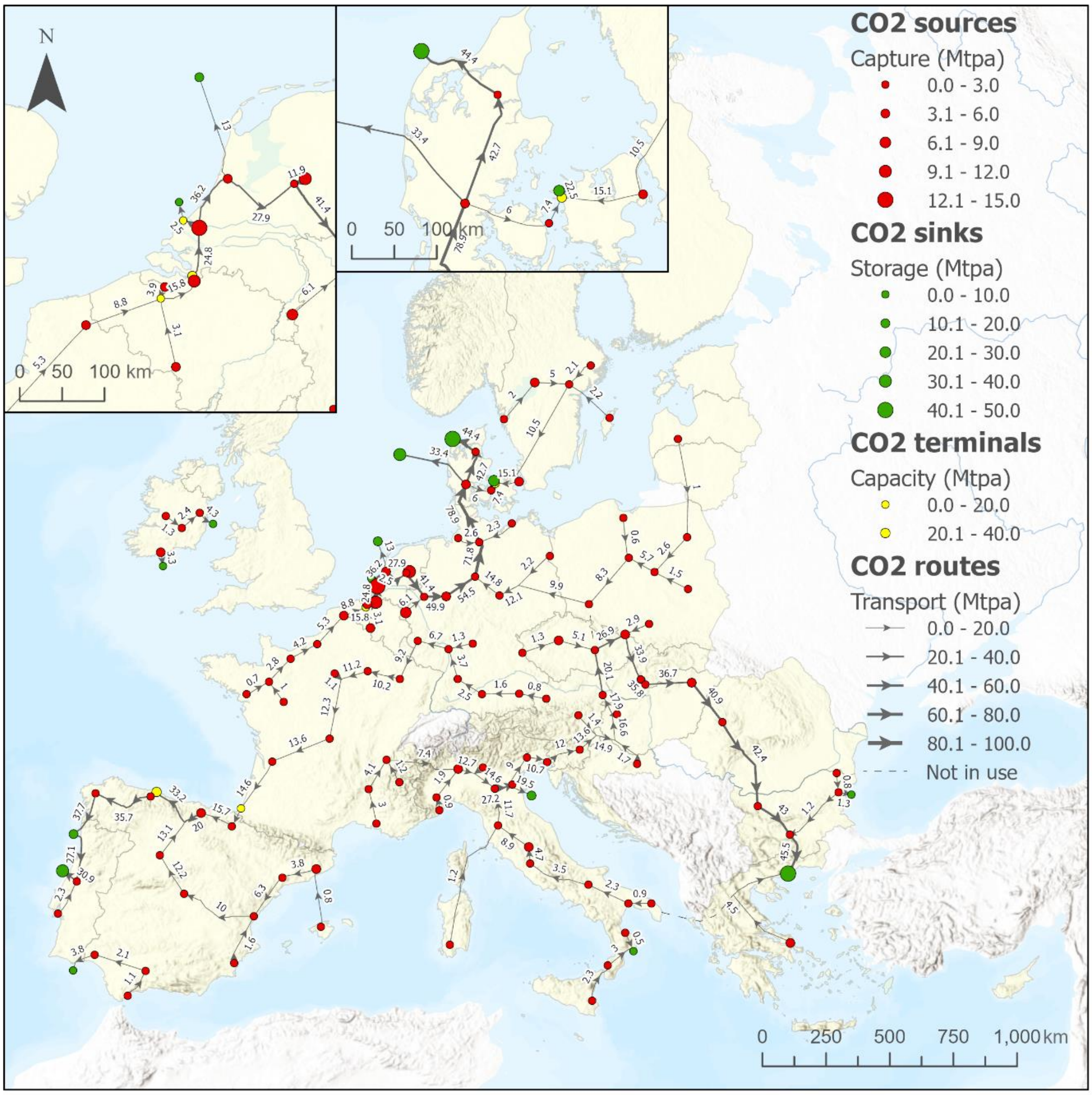


Source: JRC, 2024

In 2040, there are 111 active source nodes in 21 countries and 14 active offshore storage nodes in seven countries. The CO_2 transport network extends throughout 22 EU countries with 26 cross-border connections.

The length of the network is 19 000 km. Parts of the network represented by the dashed lines on the map (Figure 16) represent the infrastructure not used for the CO_2 transport anymore. They were built to transport the excess of captured CO_2 in Greece to the North Sea storage nodes and to transport CO_2 captured in central Europe to the North Sea region. In 2040, with more storage capacity available closer to the source locations, they became unnecessary. Due to a lack of sufficient storage capacity in the EU part of the North Sea, the captured CO_2 in central Europe is being transported to the CO_2 sink node in Greece. In addition to a significant amount of CO_2 stored in the North Sea region and Greece, CO_2 is also stored notable amounts in the Northern Adriatic and off the coast of Portugal. These four main storage areas determine the four main parts of the CO_2 transport network.

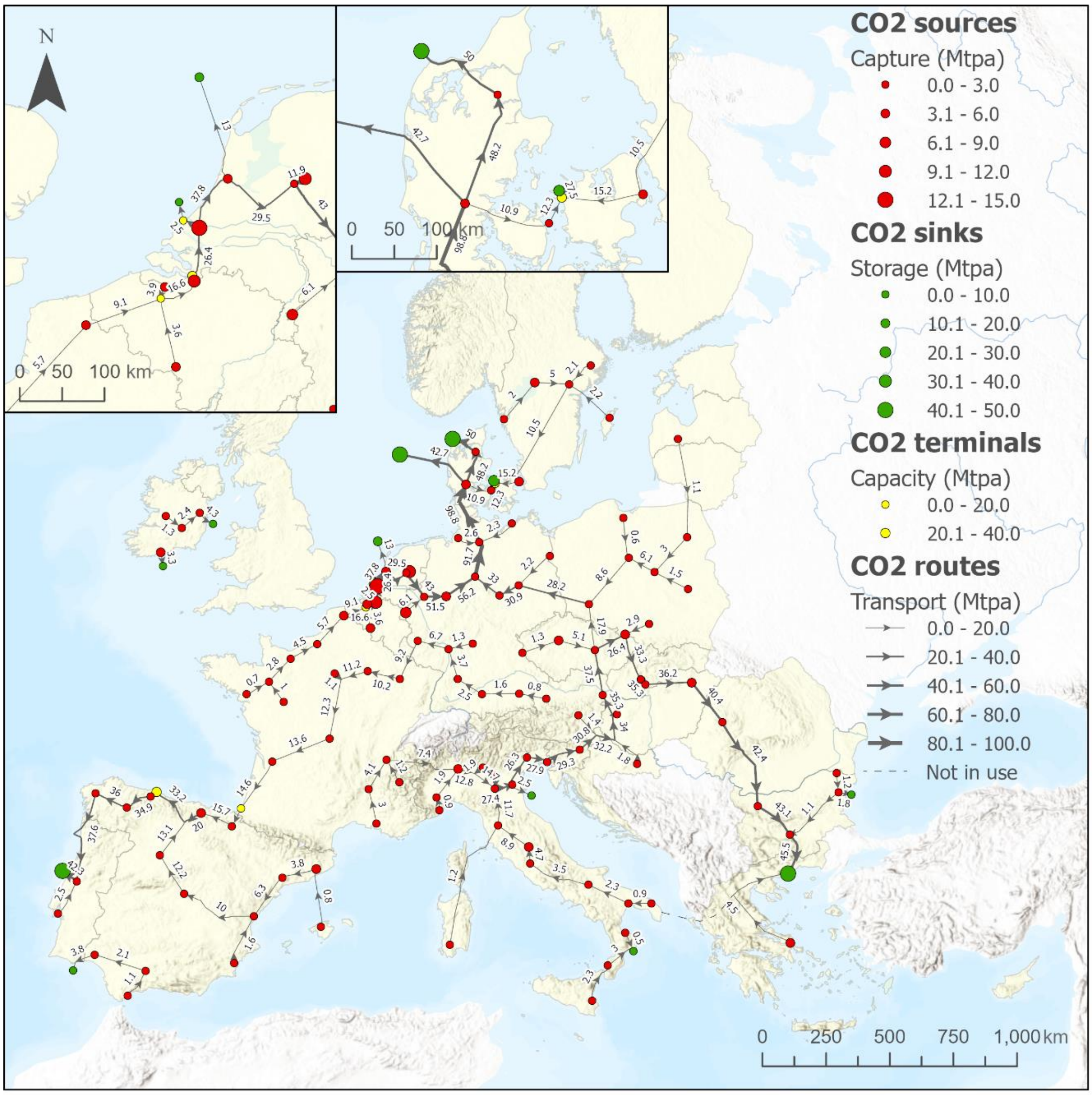
Figure 16. Scenario B1 - CTP 2040 & Offshore only (EU), year 2040



Source: JRC, 2024

In 2050, the transport network extends to 22 countries with 27 cross-border connections. The total length of the network is about 19 000 km. The captured CO_2 is stored in 13 active sink nodes in seven countries. CO_2 is being stored in the lowest number of countries, with the lowest number of active CO_2 storage nodes. Compared to the other scenarios, B1 has the longest network because there are limited options to store CO_2 restricted only to the EU offshore locations.

Figure 17. Scenario B1 - CTP 2040 & Offshore only (EU), year 2050



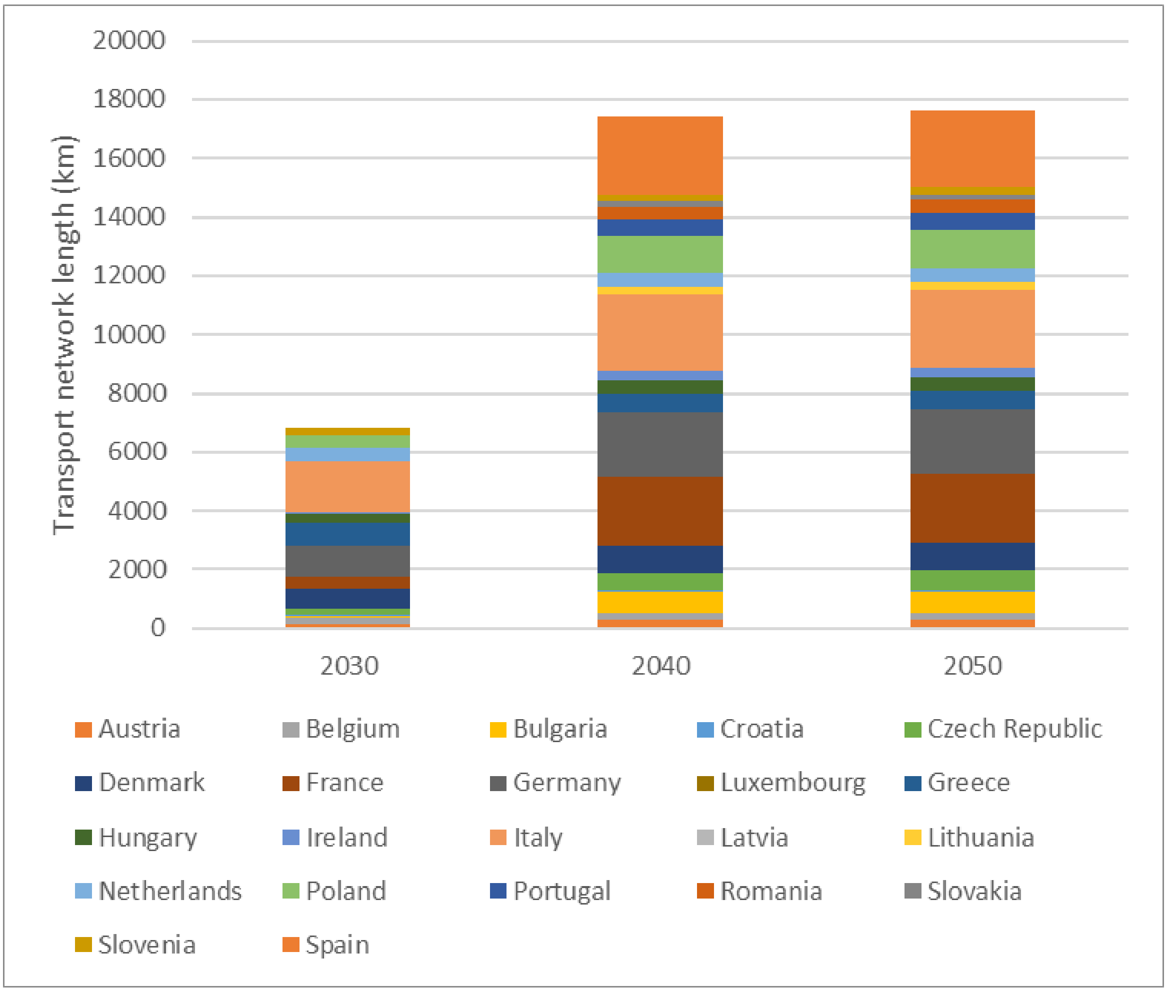
Source: JRC, 2024

The transport of relatively small amounts of CO_2 is developed from several island nodes to the mainland (e.g. 1.2 Mtpa from Sardinia and 0.8 Mtpa from the Balearic Islands). Instead of building a pipeline infrastructure for the transport of the CO_2, it is also an option to use shipping. However, the analysis does not provide a specific solution regarding the choice between offshore pipeline and shipping. Other options involve finding local storage solutions or other means of decarbonisation, if feasible.

Also in this scenario, there are parts of the network (marked with dashed lines) not used for the CO_2 transport anymore.

Figure 18 shows the distribution of the length of the transport network used per country during the observed period.

Figure 18. Transport network length per country, scenario B1 - CTP 2040 & Offshore only (EU)

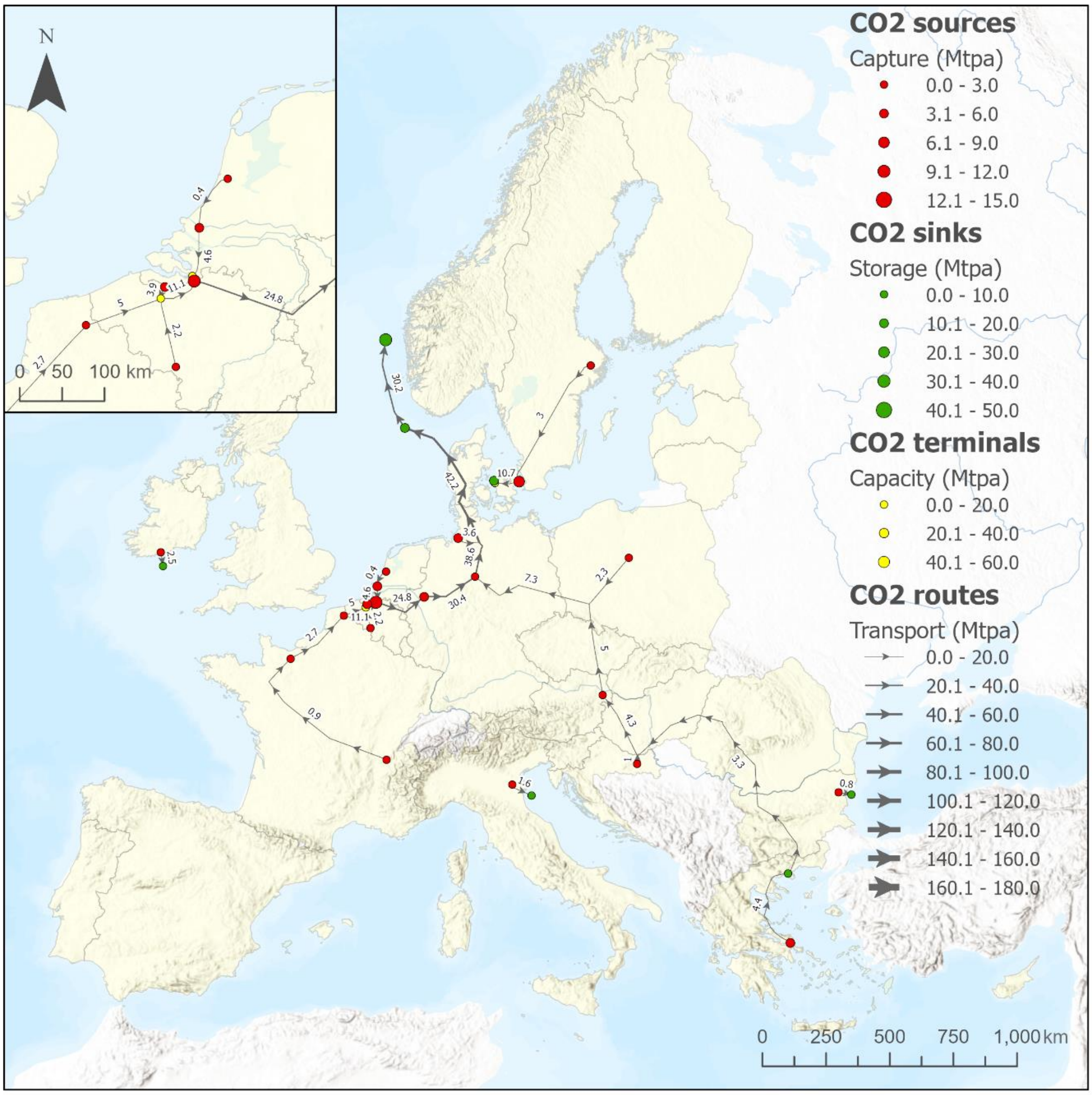


Source: JRC, 2024

4.5 Scenario B2 - CTP 2040 & Offshore only (EU+NO+UK)

Scenario B2 assumes that the CO_2 captured in the EU can be stored only in the offshore storage locations in EU, Norway and the UK. Compared to the previous scenario, there are more potential CO_2 storage locations and more potential CO_2 storage capacity. This allows the EU to avoid issues with ensuring sufficient storage capacity during the early phase of network development.

Figure 19. Scenario B2 - CTP 2040 & Offshore only (EU+NO+UK), year 2030

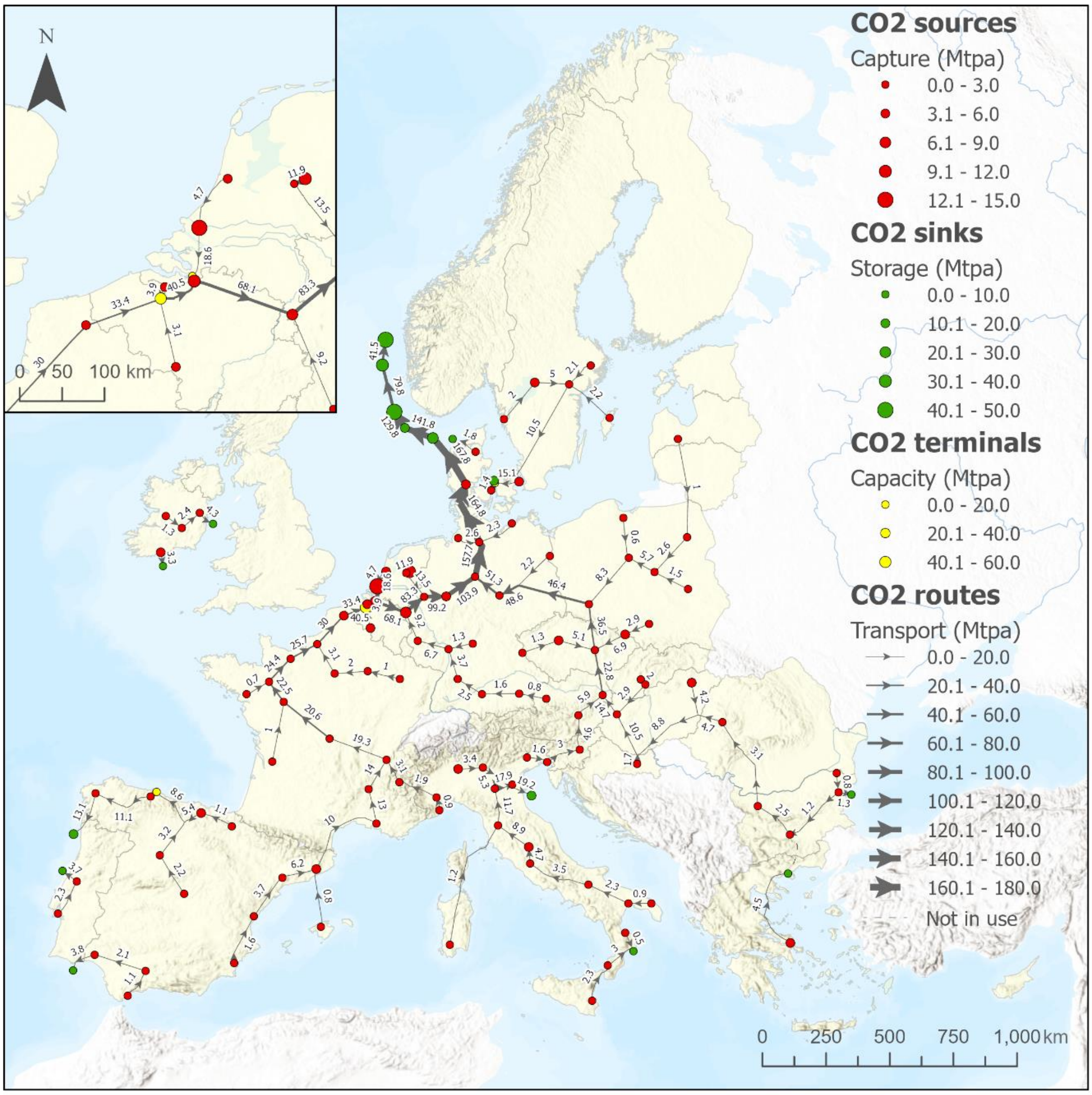


Source: JRC, 2024

The early phase of the CO_2 transport network development is almost identical to scenarios A2 and A3. As in these scenarios, in 2030, the major part of the network is developed in the North Sea region. A long route is connecting the CO_2 sources in Greece and the storage locations in the North Sea since there are no active storage locations with sufficient storage capacity closer to the sources. This long route also collects and transports CO_2 captured in Croatia, Austria and Poland. In addition, the optimisation results in a developed route transporting relatively small amounts of CO_2 captured in south-eastern France to the North Sea region.

The CO_2 transport network extends to 17 countries while CO_2 is captured in 13 and stored in six countries.

Figure 20. Scenario B2 - CTP 2040 & Offshore only (EU+NO+UK), year 2040

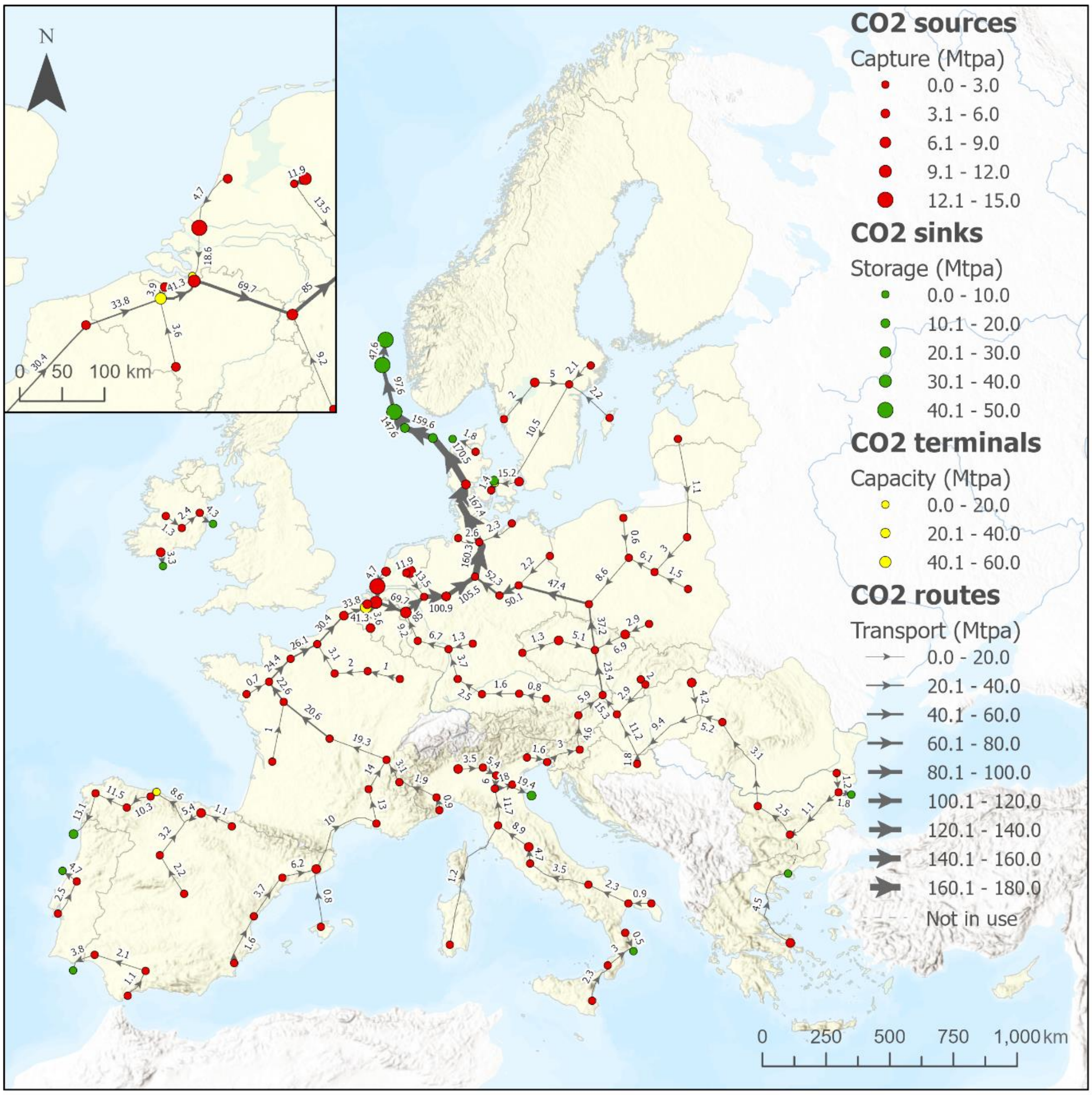


Source: JRC, 2024

In 2040, the development no longer follows the same path since in this scenario, only offshore storage nodes are available. The sharp increase of the CO_2 capture (from 58.8 Mtpa in 2030 to 242.9 Mtpa in 2040) is followed by the intense development of a 16 000 km long CO_2 transport network. The longest parts of the network are in France, Spain, Italy and Germany. The network extends across 23 countries with 26 cross-border connections. CO_2 is being stored in 16 active storage nodes in seven countries.

There is a high-capacity route passing through the Netherlands, Germany and Denmark, transporting most of the CO_2 captured in the EU to the storage sites in the Norwegian part of the North Sea. The route has two main branches; one is transporting captured CO_2 from western Europe and the other from central and eastern Europe.

Figure 21. Scenario B2 - CTP 2040 & Offshore only (EU+NO+UK), year 2050



Source: JRC, 2024

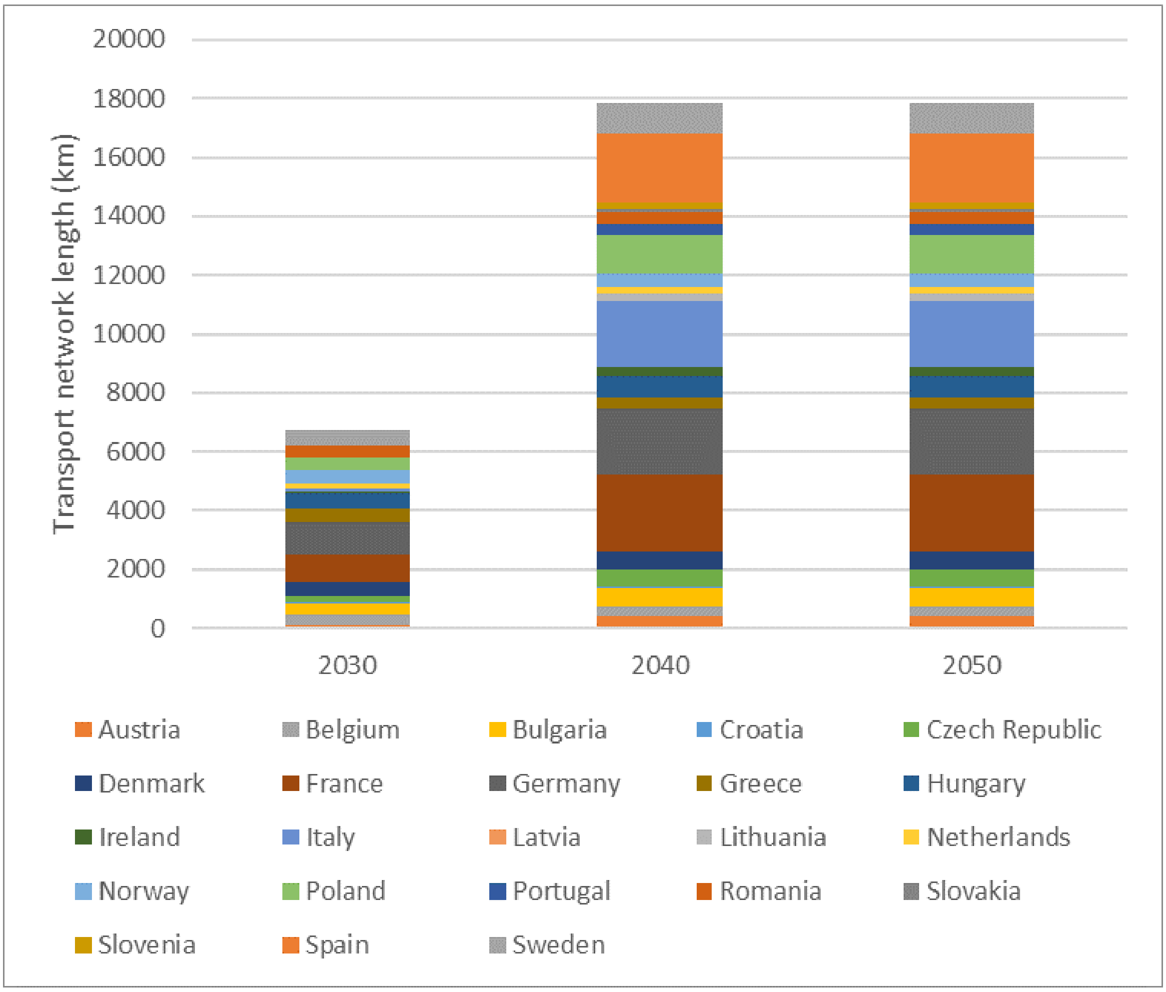
In 2050, the network length stays the same, as the CO_2 capacity increases very little. Because of the unavailability of onshore storage, the network is longer than in Scenario group A.

The main storage location is the North Sea region which stores CO_2 from almost all capture sites in Europe, while other locations are storing significantly lower CO_2 amounts (e.g. Celtic Sea, Adriatic, Black Sea), mostly from closer CO_2 sources (e.g. Portugal, Spain, Bulgaria, Greece, Ireland). In comparison with other scenarios, the North Sea region plays an even more significant role in CO_2 transport and storage.

As in the other scenarios, CO_2 starts to be captured on several islands in 2050 and the transport network develops between these and the mainland. Instead of building a pipeline infrastructure for the transport of the CO_2, it would also be an option to use shipping.

Figure 22 shows the distribution of the length of the transport network used per country during the observed period.

Figure 22. Transport network length per country, scenario B2 - CTP 2040 & Offshore only (EU+NO+UK)



Source: JRC, 2024

4.6 Scenario C1 - CTP 2040 & NZIA 2030 targets (EU)

To harmonise the values of the storage nodes, certain adjustments were made to the input data. Storage capacities of specific storage nodes were modified to fit the objective of 50 Mtpa in 2030 in the EU. This was achieved by advancing the commencement of operation for certain announced storage projects and adjusting their storage capacity development plans by one or more years. Similar adjustments were necessary for the commencement and development plans of the capture projects due to decreased storage capacity. The capture projects were selected based on their distance to storage locations, planned captured capacities and funding secured to minimise investment costs. By implementing this approach, the available storage capacity is maximally utilised (Table 5).

By making these changes, adjustments were made to the capture and storage input data during the period between 2025 and 2031. In comparison with the announced capacities, these adaptations resulted in decreased capture and storage capacities. Therefore, 75.2 Mt less of CO_2 was being stored compared to the maximum storage values in other scenarios.

Table 5. Scenario C1 - Adjustments of the input data

Year	2025	2026	2027	2028	2029	2030	2031
CO_2 captured (Mtpa)	0.55	2.15	14.31	28.82	32.51	49.68	54.24
CO_2 storage capacity (Mtpa)	0.55	2.15	14.35	28.90	32.58	49.78	54.28

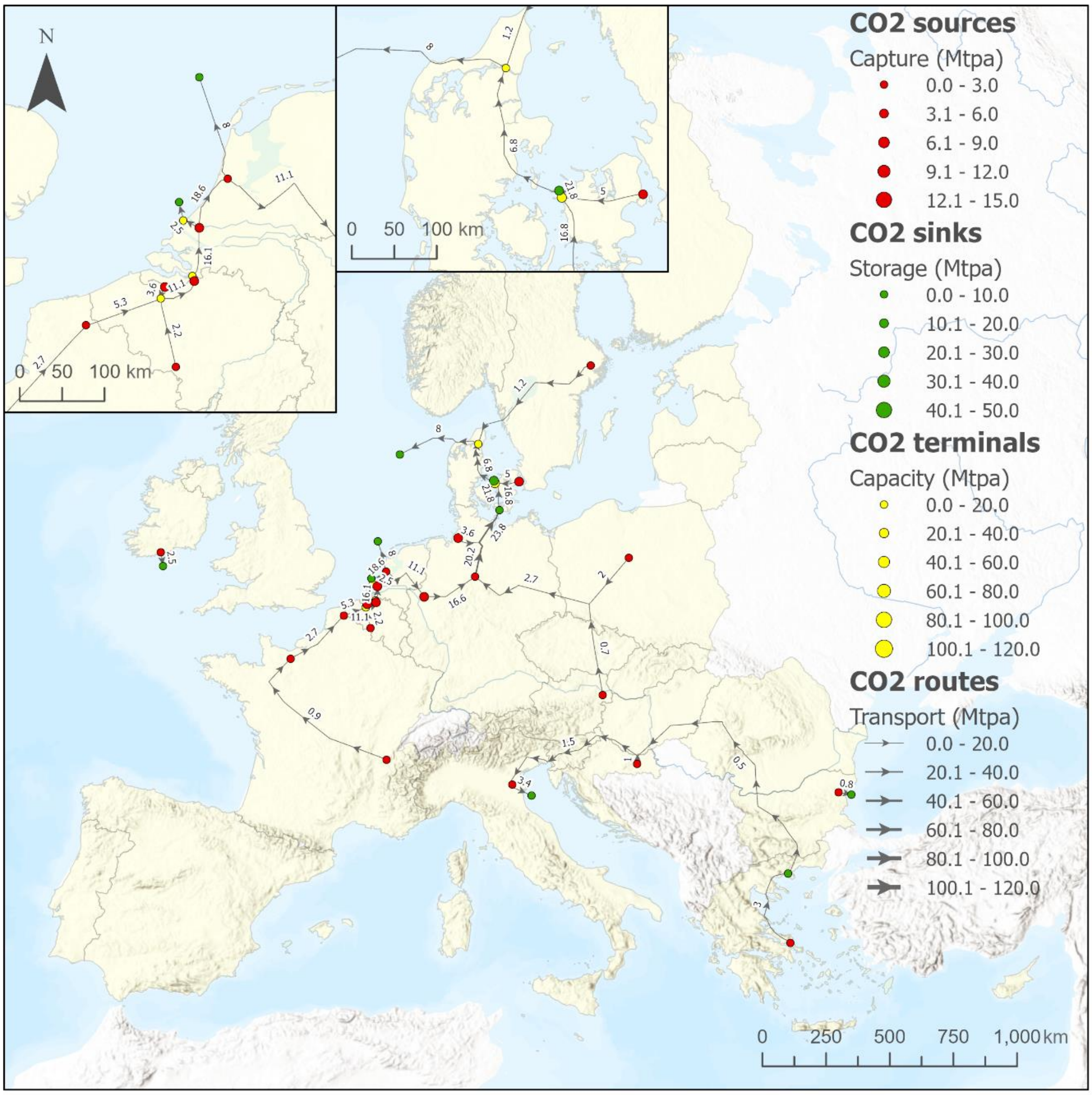
Source: JRC, 2024

Given the potential challenges that early adopters in the CCS industry might encounter, there could be notable disparities between the plans initially announced by project developers and the actual start dates. This aspect renders this scenario highly relevant both within the specific context and in the context of the NZIA proposal (European Commission, 2023).

In 2030, the network transports about 50 Mt of CO_2 captured in 13 countries to sink nodes in six countries. The total length of the network is about 7 300 km (6 500 km onshore and 700 km offshore), and the network extends across 17 countries. The early development of the network is similar to the other scenarios, but with lower capture, transported and stored capacities.

The main storage region is the North Sea. Also, CO_2 is stored in the northern Adriatic region captured in locations close to it, together with the surplus CO_2 captured in Greece where, at this moment, the storage capacity does not meet demand. However, due to storage capacity constraints, some of the CO_2 also needs to be transported towards the North Sea region, and a transport network has been formed in that direction.

Figure 23. Scenario C1 - CTP 2040 & NZIA 2030 targets (EU), year 2030

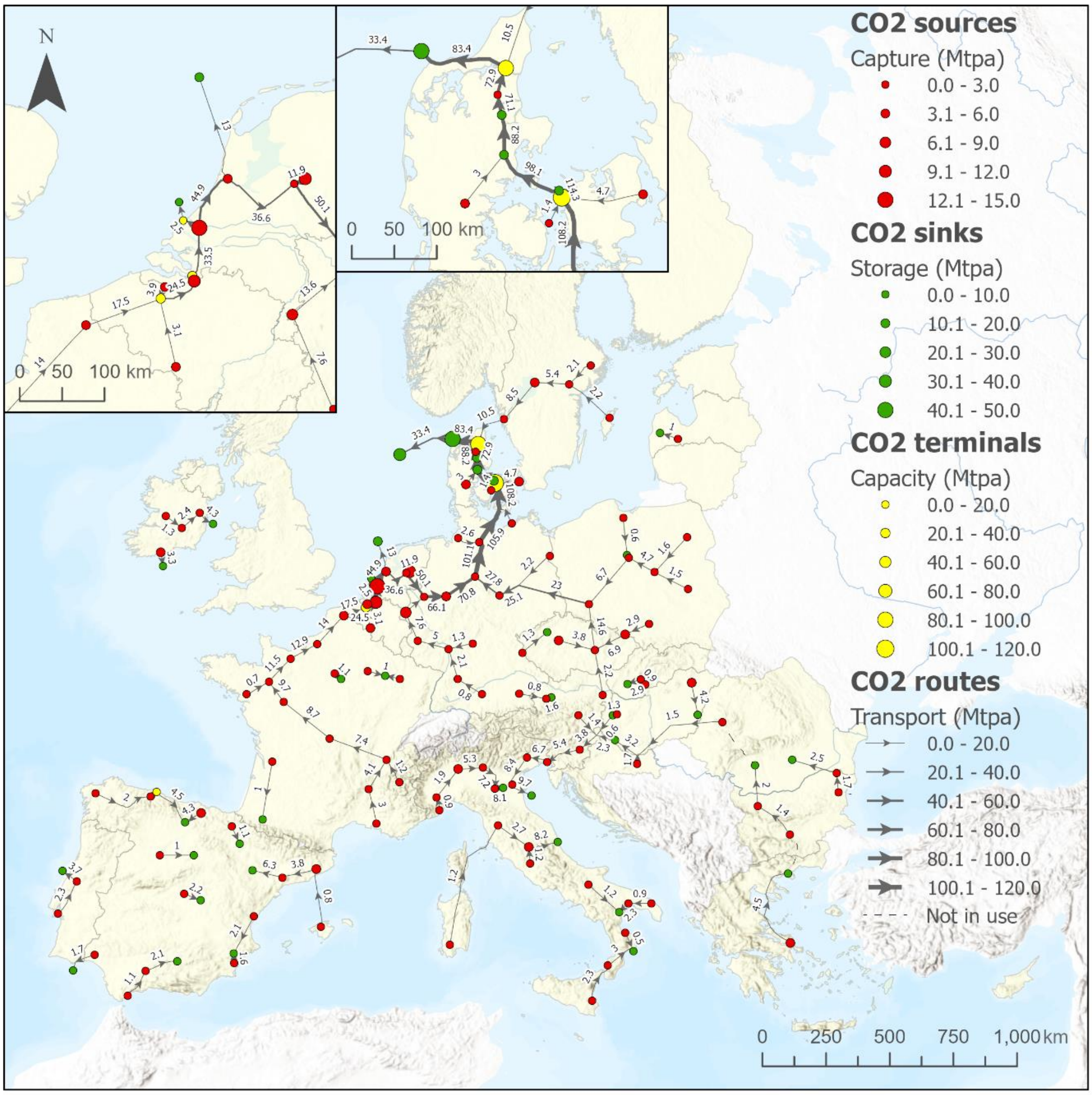


Source: JRC, 2024

In 2040, the total amount of CO_2 captured, transported and stored is the same as in other scenarios and it amounts to about 243 Mt. There are 111 active source nodes in 21 countries and 38 active storage nodes in 16 countries.

The CO_2 transport network extends throughout 21 EU countries with 24 cross-border connections. The length of the network built is 15 700 km (14 400 km onshore and 1 300 km offshore). The CO_2 transport network consists of one big segment that collects CO_2 from most countries from western and central Europe. The role of the North Sea region is still very important but not as emphatically so as in the previous scenarios. Besides the above-mentioned segment of the transport network, there are several smaller regional networks and more routes connecting individual source and storage nodes. Due to limited storage capacity in the EU part of the North Sea region, additional storage nodes were activated in the southern part of Europe.

Figure 24. Scenario C1 - CTP 2040 & NZIA 2030 targets (EU), year 2040

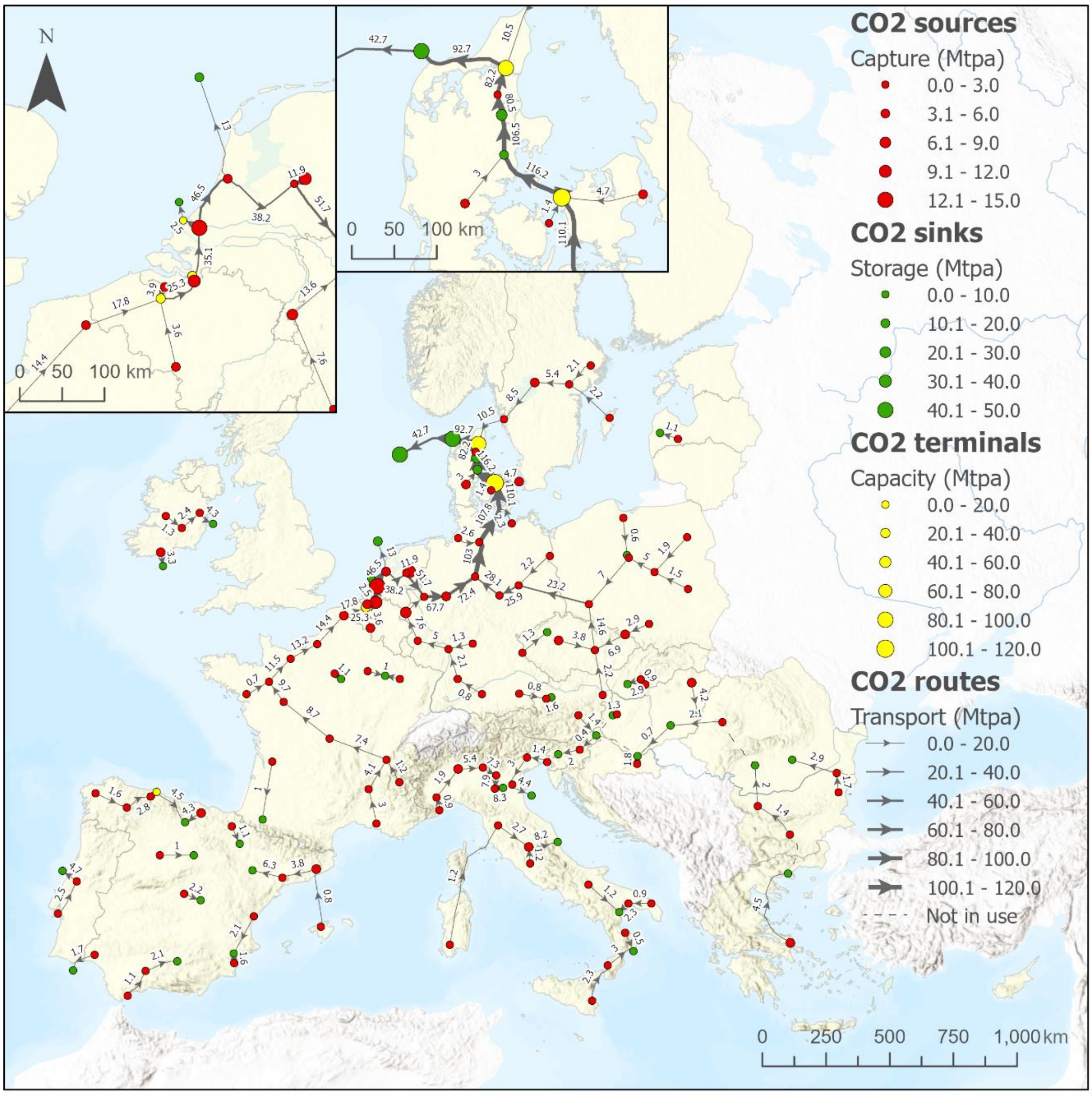


Source: JRC, 2024

In 2050, there are no significant changes as there is also no significant increase in CO_2 in the network. The transport network still consists of one major segment and many smaller segment connecting individual or multiple capture nodes with storage nodes.

The transport of relatively small amounts of CO_2 is developed from several island nodes to the mainland (e.g. 1.2 Mtpa from Sardinia and 0.8 Mtpa from the Balearic Islands). Instead of building a pipeline infrastructure for the transport of the CO_2, it is also an option to use shipping. However, the analysis does not provide a specific solution regarding the choice between offshore pipeline and shipping. Other options involve finding local storage solutions or other means of decarbonisation, if feasible.

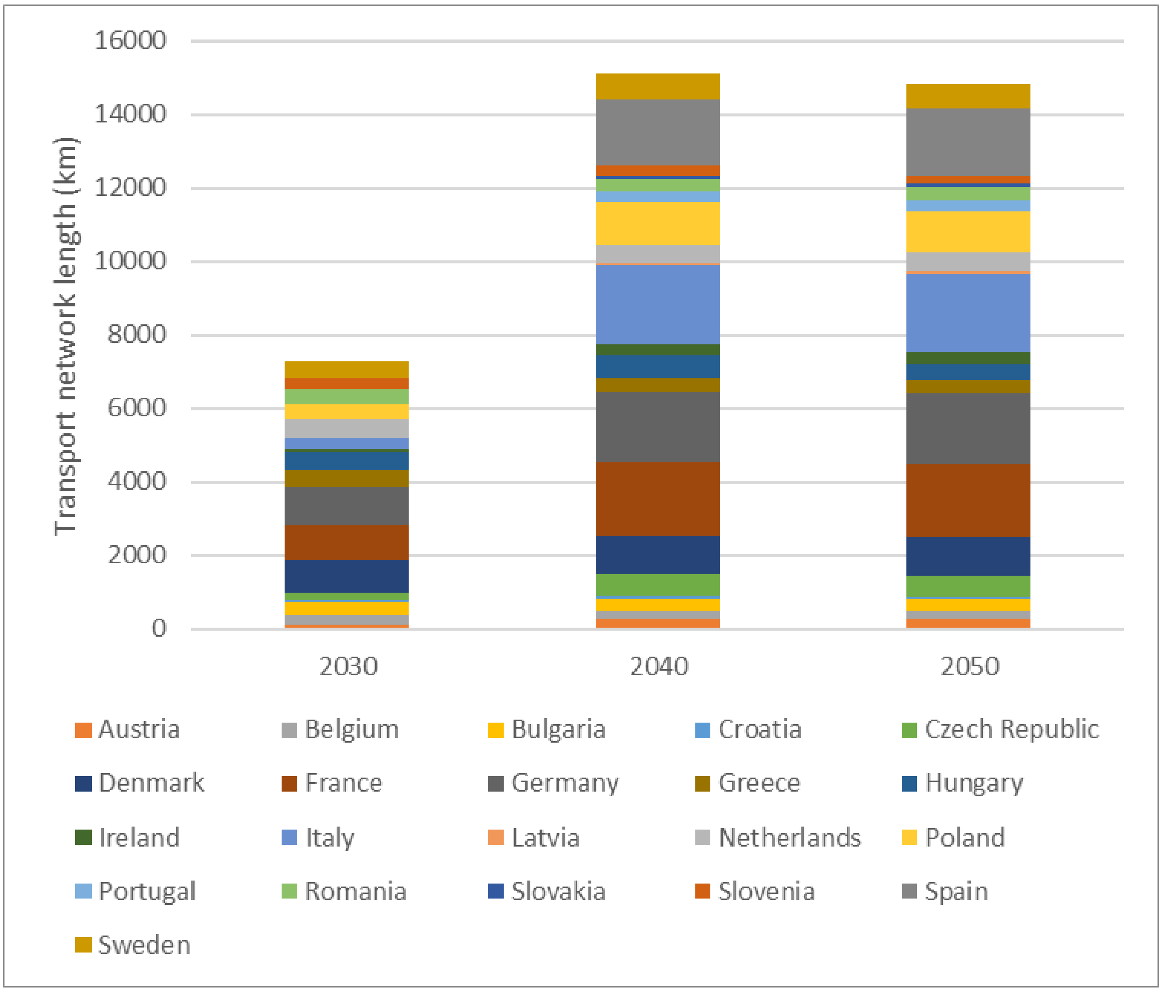
Figure 25. Scenario C1 - CTP 2040 & NZIA 2030 targets (EU), year 2050



Source: JRC, 2024

Figure 26 shows the distribution of the length of the transport network used per country during the observed period.

Figure 26. Transport network length per country, scenario C1 - CTP 2040 & NZIA 2030 targets (EU)



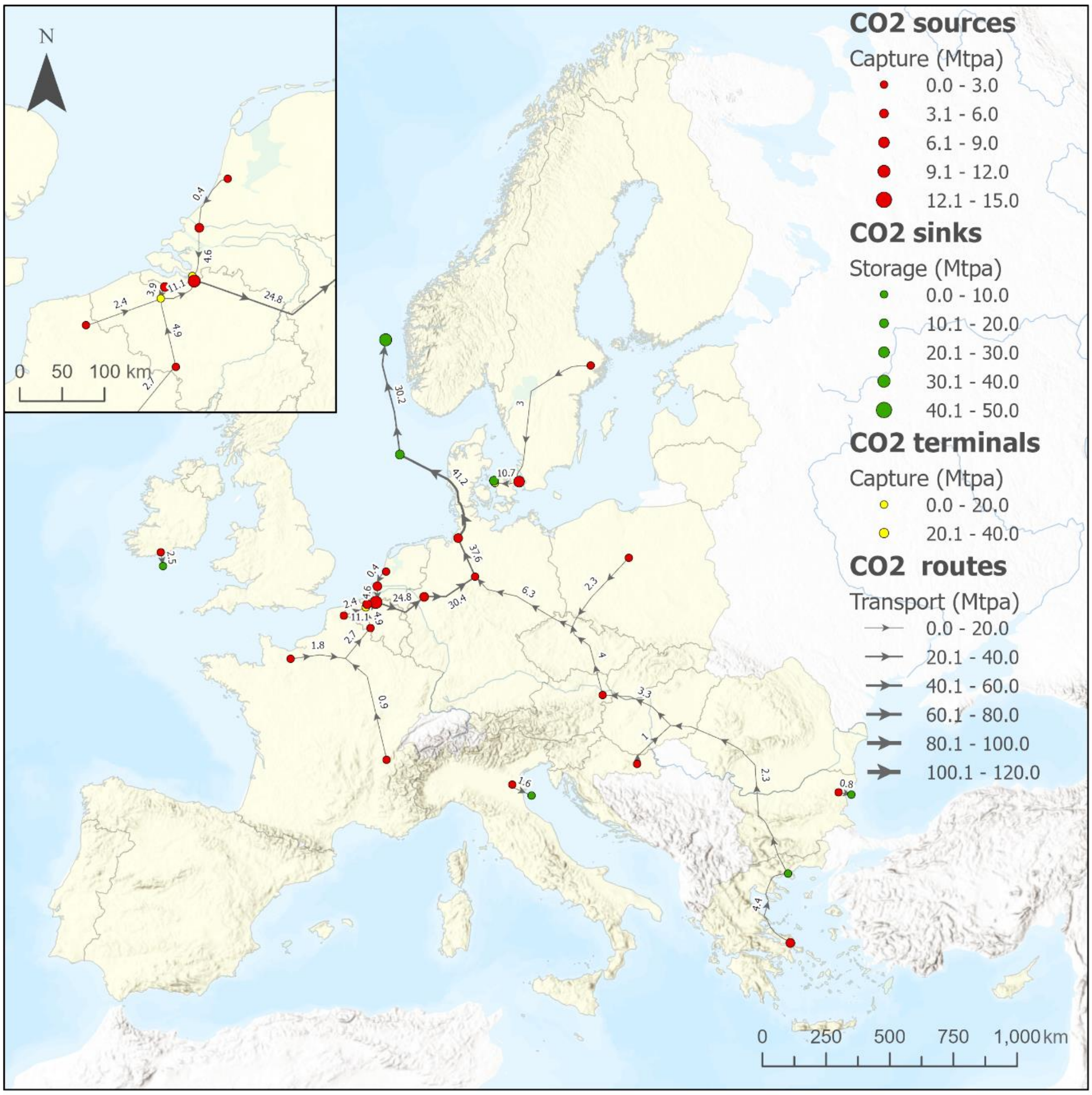
Source: JRC, 2024

4.7 Scenario D1 - Fit-for-55 (EU+NO+UK)

Scenario D1 investigates the development of the CO_2 transport network based on CO_2 capture projections taken from the modelling results of the full package scenario for the Fit-for-55 exercise. Captured CO_2 can be stored in the EU, Norway, and the UK. Based on the underlying assumptions, this scenario is equivalent to scenario A3.

According to the full package scenario, the amount of CO_2 that needs to be stored is increasing at a slower rate compared to CTP 2040 modelling (Table 1).

Figure 27. Scenario D1 - Fit-for-55 (EU+NO+UK), year 2030

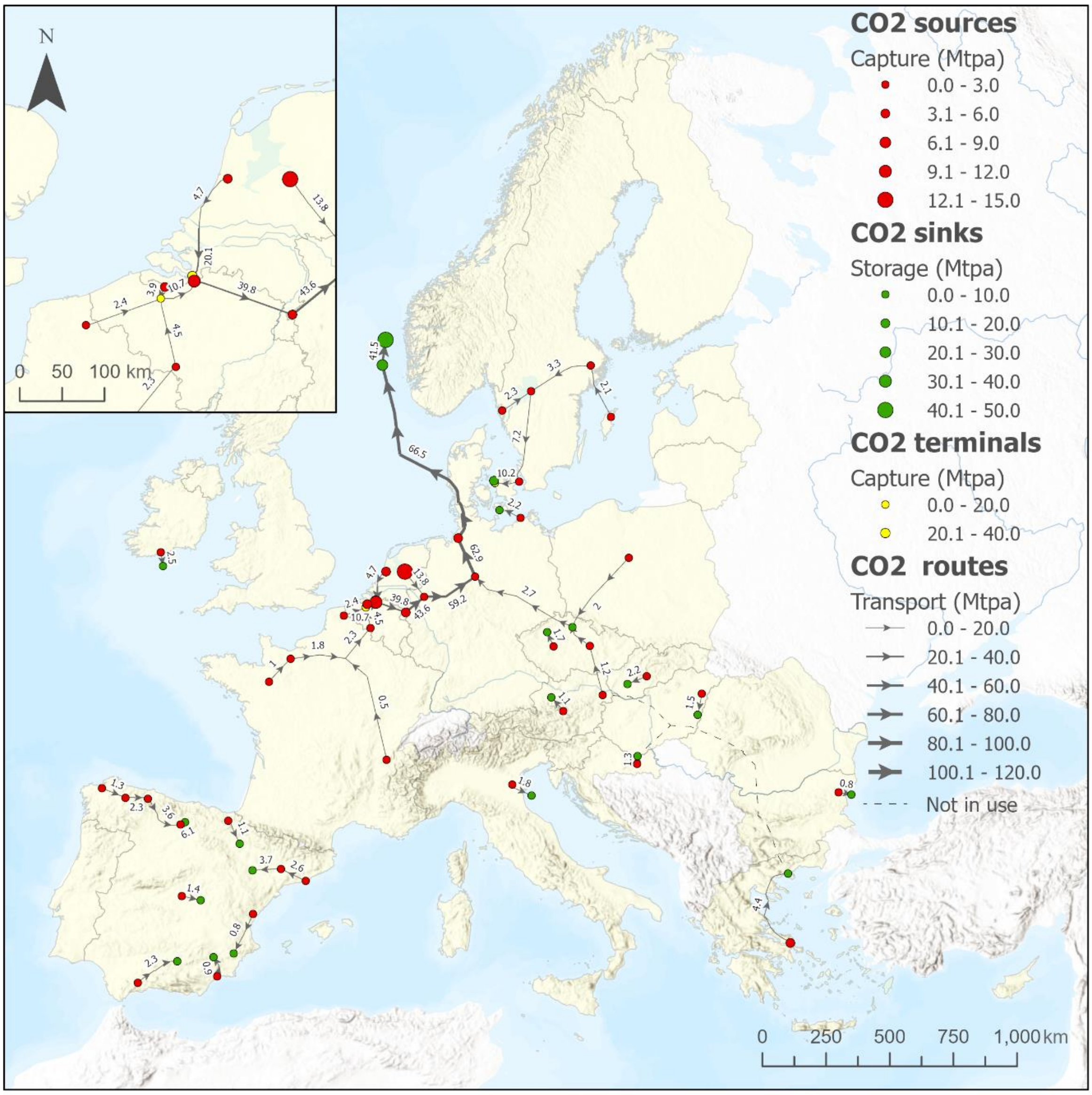


Source: JRC, 2024

The CO_2 transport network development is concentrated around the North Sea region with two branches that transport captured CO_2 from the southern parts of Europe. One branch extends towards south-eastern France, and the other through central Europe towards Greece. Both serve to transport excess of captured CO_2, the quantity of which is too large for the available storage capacities in that part of Europe.

The CO_2 transport network extends to 18 countries and the total network length amounts to 6 500 km (5 600 km onshore and 900 km offshore). There are seven active storage nodes in seven countries.

Figure 28. Scenario D1 - Fit-for-55 (EU+NO+UK), year 2040



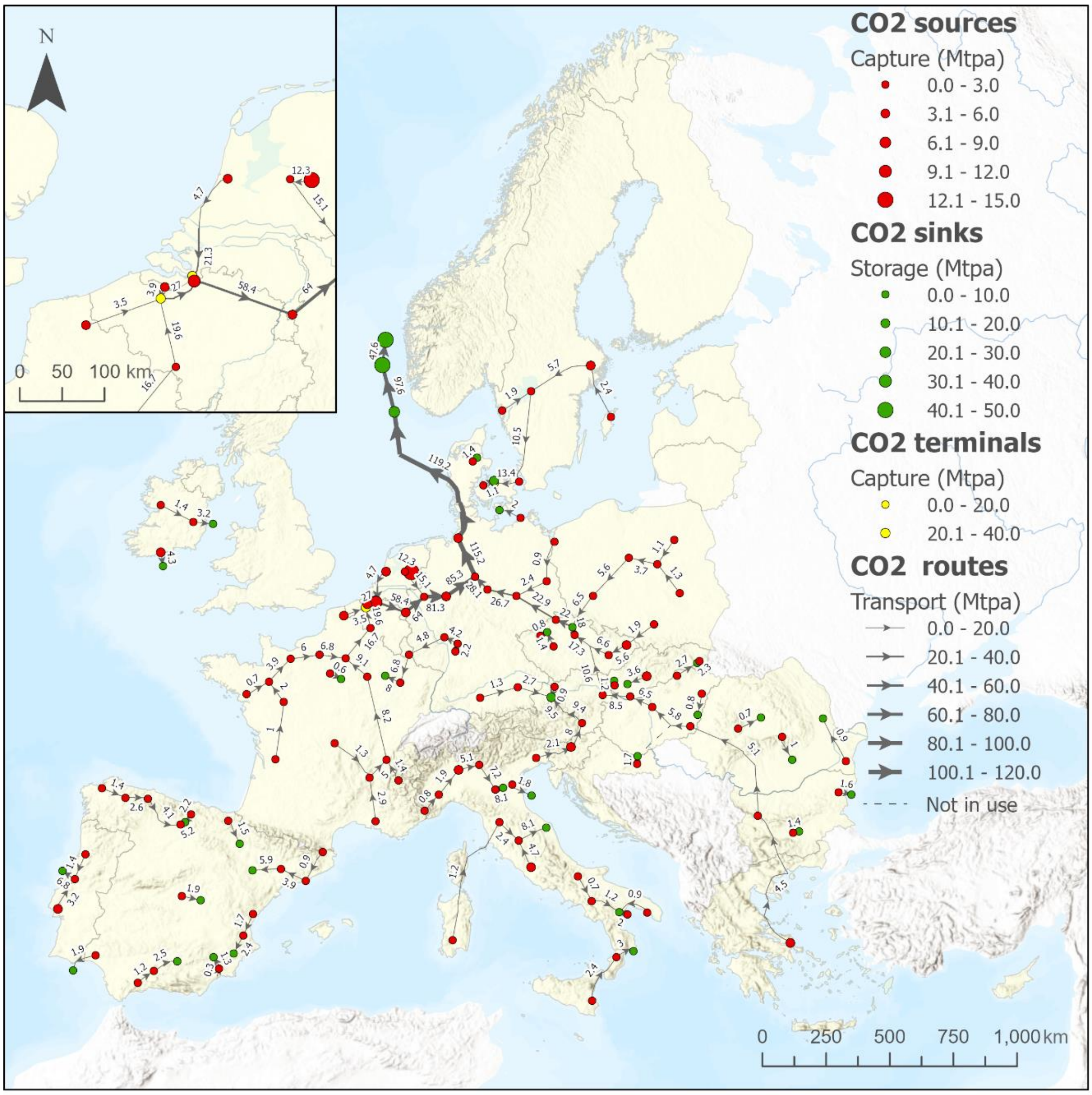
Source: JRC, 2024

In 2040, there is an increase in captured CO_2 from about 59 Mtpa to 114 Mtpa. Compared to the scenarios based on 2040 CTP modelling results, this scenario shows a lower increase in captured CO_2 between 2030 and 2040, which is reflected in the smaller scale of the network development.

The main storage region is the North Sea, where CO_2 from western Europe and some of the CO_2 from central Europe is stored. The previously constructed transport network that connected distant southern sources to the North Sea is currently not in use. The reason for this is that during the period between 2030 and 2040, storage nodes with sufficient capacity and closer-to-source nodes were activated.

The CO_2 transport network extends to 18 countries and the total length amounts to 8 800 km, of which 7 400 km are used in 2040 as outlined above. There are 43 active source nodes in 17 countries and 21 active sink nodes in 12 countries.

Figure 29. Scenario D1 - Fit-for-55 (EU+NO+UK), year 2050



Source: JRC, 2024

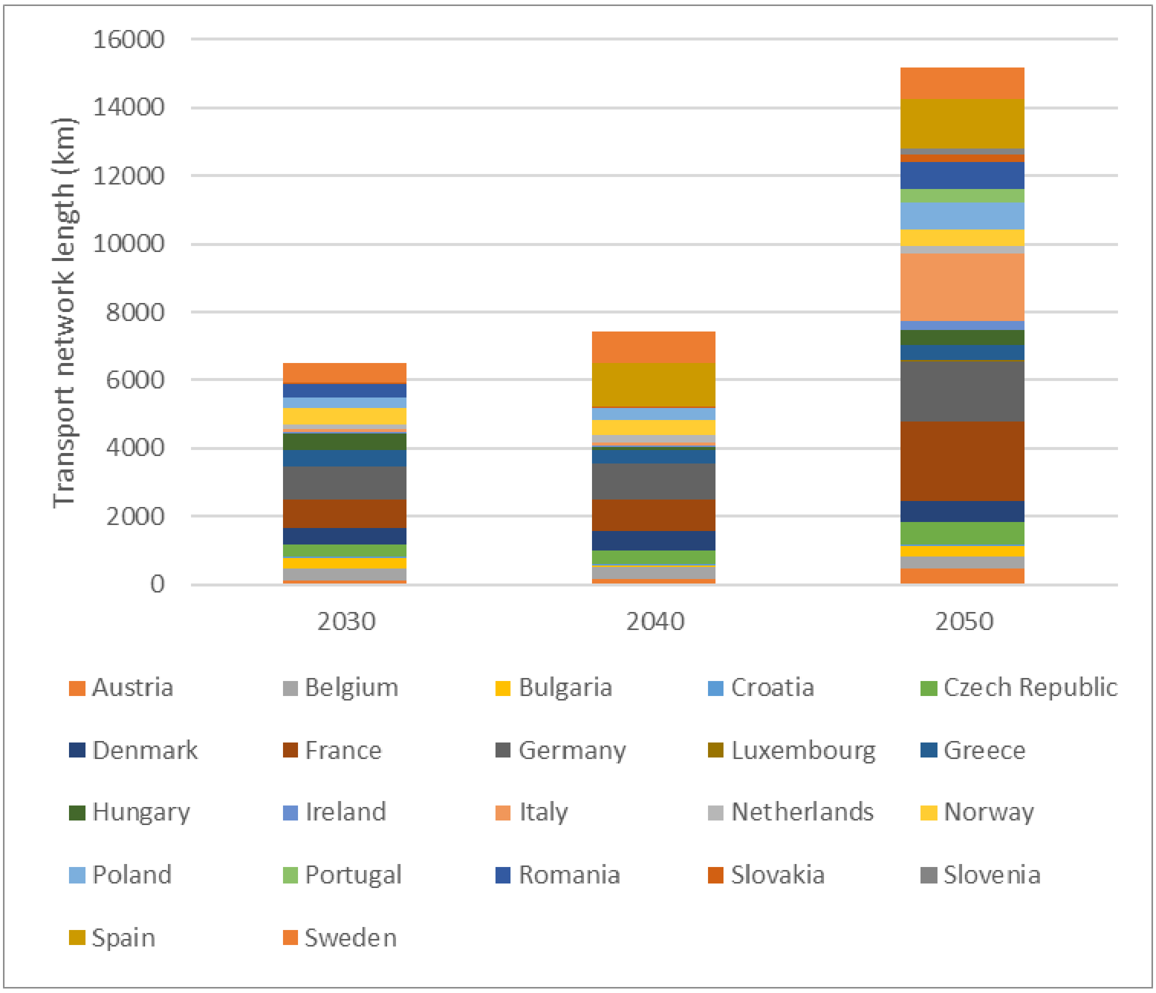
In 2050, the CO_2 transport network takes a form very similar to the networks of other scenarios in 2040. The CO_2 transport network extends across the EU (around 15 300 km and 22 countries) and transports about 245 Mtpa of captured CO_2. The main storage region is the North Sea, but CO_2 is also being stored in a significant number of CO_2 sink nodes (37) across Europe.

A high-capacity route is passing through the Netherland, Germany and Denmark, transporting most of the CO_2 captured in the EU to the storage sites in the Norwegian part of the North Sea. The route has two main branches; one is transporting captured CO_2 from western Europe and the other from central and eastern Europe.

Although the storage locations in the UK have significant storage capacity and are relatively close to a large number of CO_2 sources in the EU, the results showed that they were not used during the observed period. Since they become available after 2035, the main transport infrastructure is already developed and directed mostly towards storage locations in Norway.

Figure 30 shows the distribution of the length of the transport network used per country during the observed period.

Figure 30. Transport network length per country, scenario D1 - Fit-for-55 (EU+NO+UK)



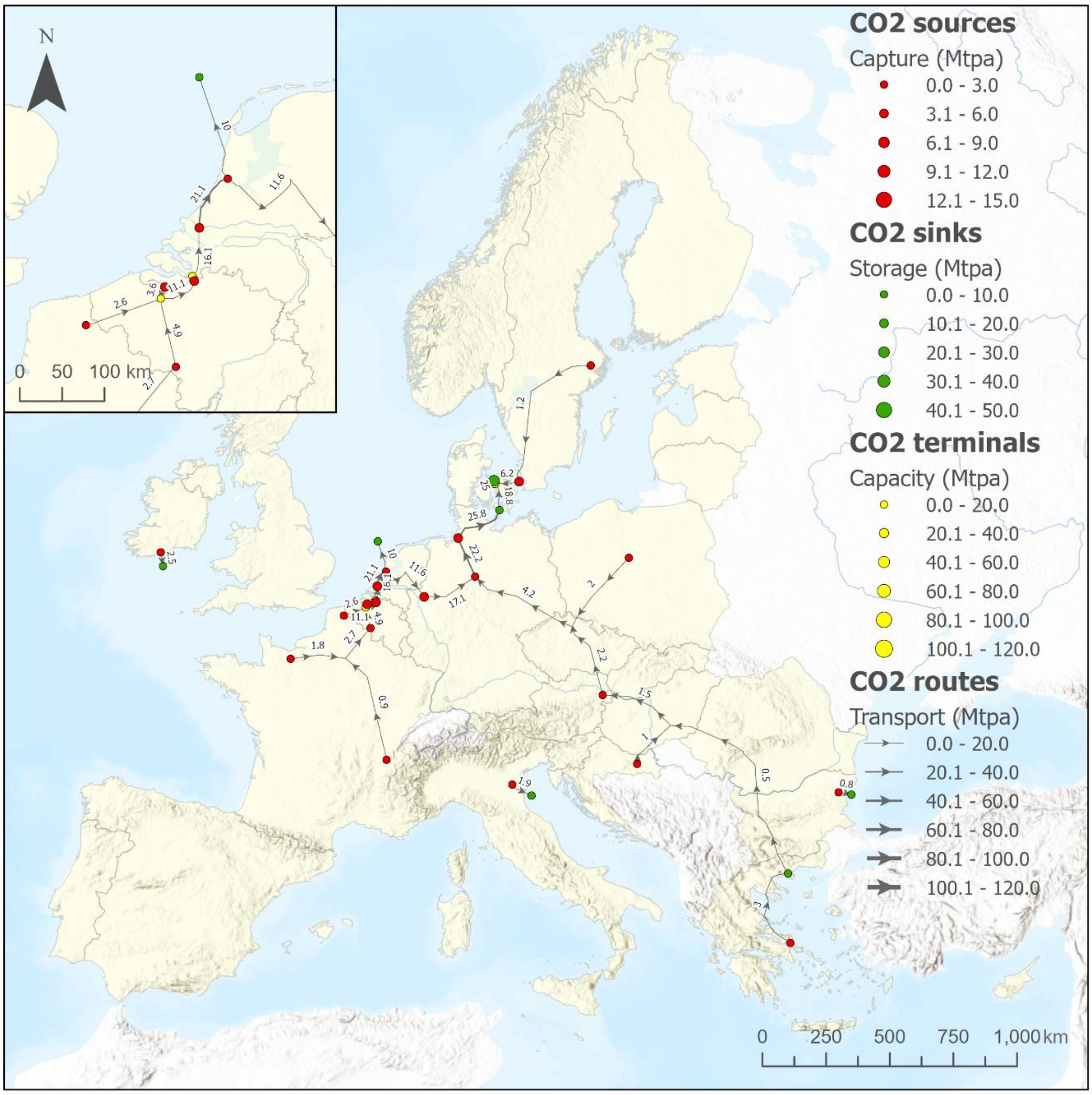
Source: JRC, 2024

4.8 Scenario D2 - Fit-for-55 & NZIA 2030 targets (EU)

Scenario D2 has the same underlying assumptions as scenario C1. It investigates the development of the CO_2 infrastructure network in the EU by reflecting the storage capacity objective of 50 Mtpa in the EU by 2030, as proposed in the Net-Zero Industry Act (European Commission, 2023). Available storage capacities can be located only in the EU. For the period after 2035, the CO_2 capture projections are taken from the Fit-for-55 modelling results.

The same adjustments had to be made as in scenario C1. Storage capacities of specific storage nodes were modified to fit the objective of 50 Mtpa in 2030 in the EU. Similar adjustments were necessary for the commencement and development plans of the capture projects due to decreased storage capacity. The capture projects were selected based on their distance to storage locations, planned captured capacities and funding secured to minimise investment costs. By implementing this approach, the available storage capacity is maximally utilised. By making these changes, about 75.2 Mt less of CO_2 was being stored compared to the maximum value that was stored in the previous scenario.

Figure 31. Scenario D2 - Fit-for-55 & NZIA 2030 targets (EU), year 2030



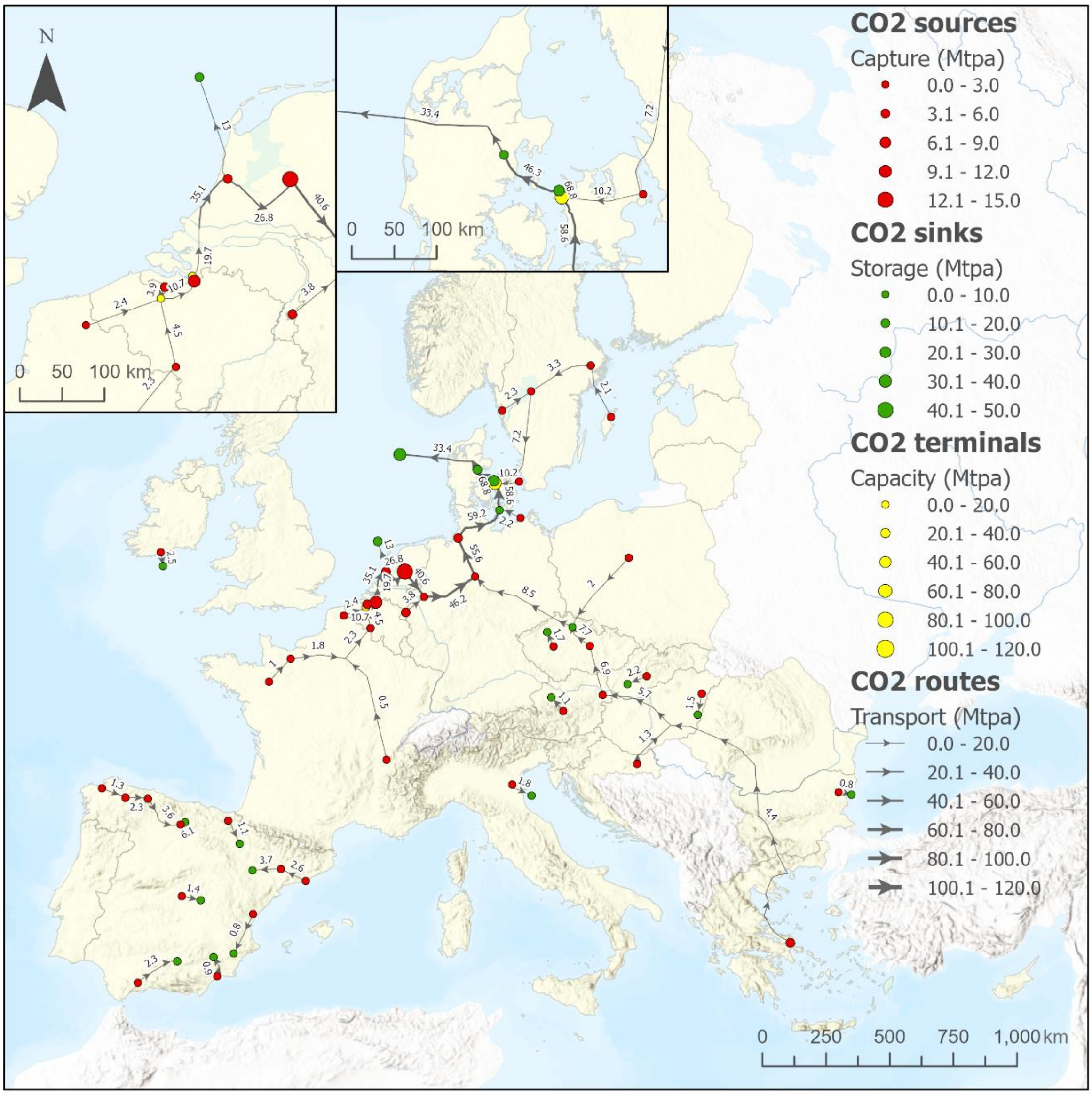
Source: JRC, 2024

The development of the CO_2 transport network is almost the same as in the previous scenario. The main difference relates to the location of storage nodes used. In this scenario, storage nodes are used in Denmark and the Netherlands, instead of in Norway as in the previous scenario.

With the exception of three source-sink pairs in Bulgaria, Ireland and Italy, the rest of the network is made up of a single segment.

The CO_2 transport network extends to 17 countries, the total network length amounts to 6 000 km and there are 16 cross-border connections. There are seven active storage nodes in six countries.

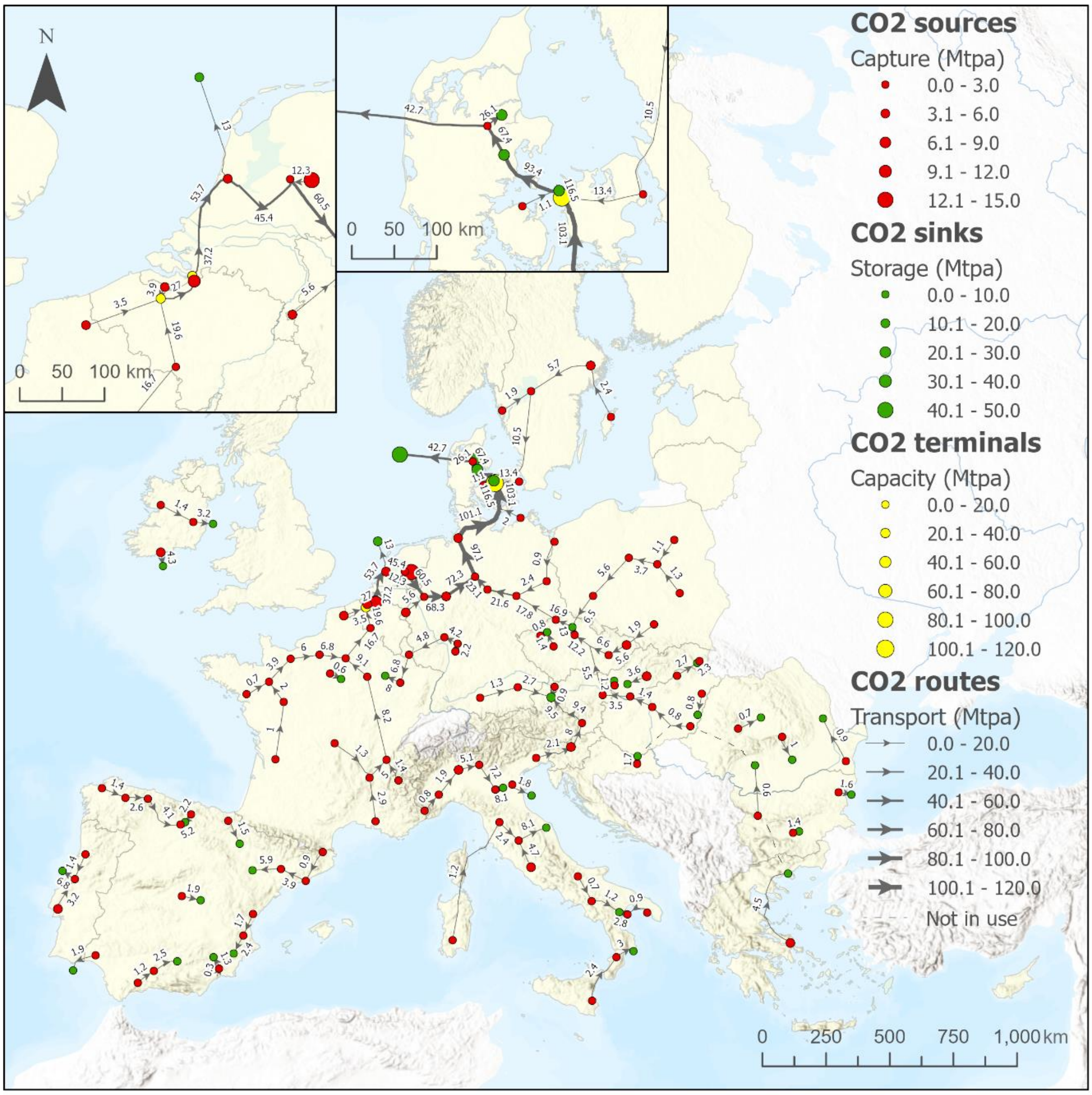
Figure 32. Scenario D2 - Fit-for-55 & NZIA 2030 targets (EU), year 2040



Source: JRC, 2024

In 2040, there is a significant development of the network in Spain, Sweden and central Europe. The transport network is now about 8 700 km long and CO_2 is captured in 43 active source nodes in 17 countries and stored in 18 active storage nodes in 10 countries. Compared to the previous period, the main structure of the network is very similar. All previously built parts of the transport network are being used.

Figure 33. Scenario D2 - Fit-for-55 & NZIA 2030 targets (EU), year 2050



Source: JRC, 2024

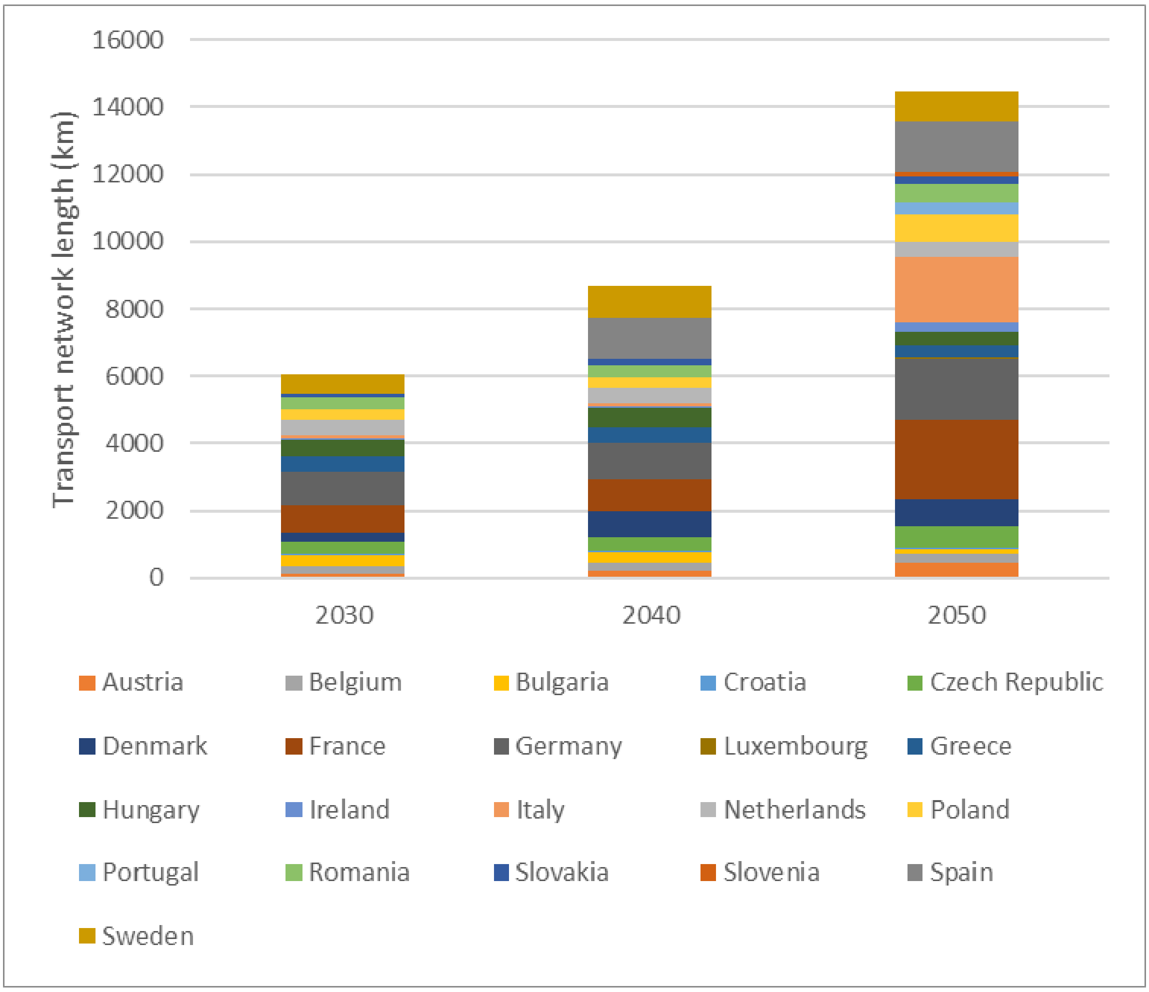
In 2050, the transport network extends to 21 countries with 25 cross-border connections. The total length of the network is about 15 200 km. CO_2 is being captured in 120 active source nodes in 21 countries. It is being stored in 38 active sink nodes in 15 countries, which is the highest number of all scenarios. The large number of countries where CO_2 is stored indicates a significant spatial distribution of CO_2 storage. However, the North Sea region remains the most important storage area.

In this and the previous scenario, a source node was not established on the Balearic Islands. The transport route with a capacity of 1.2 Mtpa is developed from Sardinia to the mainland. Instead of building a pipeline infrastructure for the transport of the CO_2, it would also be an option to use shipping.

The longest parts of the network are located in France, Italy, Germany and Spain.

Figure 34 shows the distribution of the length of the transport network used per country during the observed period.

Figure 34. Transport network length per country, scenario D2 - Fit-for-55 & NZIA 2030 targets (EU)



Source: JRC, 2024

4.9 Summary of the results

The key figures summarising the evolution of the extent and investment requirements of a trans-European CO_2 transport network over time are summarised in the following table and graphs.

Table 6 shows the total projected amounts of CO_2 captured, transported and stored between 2025 and 2050. Compared to the other scenarios, scenarios C1 and D2 - due to adjustments that had to be made to fit the 50 Mtpa storage capacity objective in 2030 as outlined in the NZIA proposal - have different total projected amounts of CO_2. Also, there is a difference depending on whether the scenarios are based on CTP 2040 or Fit-for-55 modelling. The total projected amounts of CO_2 captured, transported and stored increase from 49.7 Mtpa (NZIA) and 58.8 Mtpa (other scenarios based on the announced projects) in 2030 to 113.7 Mtpa (Fit-for-55) and 242.9. Mtpa (CTP 2040) in 2040, and 245.3 Mtpa (Fit-for-55) and 247.2 Mtpa (CTP 2040) in 2050.

Table 6. Total CO_2 captured, transported and stored per year between 2025 and 2050

Scenarios	CO_2 projections (Mtpa)		
	2030	2040	2050
A1 - CTP 2040 (EU)	58.8	242.9	247.2
A2 -CTP 2040 (EU+NO)	58.8	242.9	247.2
A3 -CTP 2040 (EU+NO+UK)	58.8	242.9	247.2
B1 - CTP 2040 & Offshore only (EU)	33.9	242.9	247.2
B2 - CTP 2040 & Offshore only (EU+NO+UK)	58.8	242.9	247.2
C1 - CTP 2040 & NZIA targets (EU)	49.7	242.9	247.2
D1 - Fit-for-55 (EU+NO+UK)	58.8	113.7	245.3
D2 - Fit-for-55 & NZIA targets (EU)	49.7	113.7	245.3

Source: JRC, 2024

The lowest total amount of CO_2 is stored in scenario B1, and the highest in scenarios A2, A3 and B2 in CTP 2040 group of scenarios. In Fit-for-55, more CO2 is stored in D1 scenario (Table 7).

Table 7. Total CO_2 stored between 2025 and 2050

Scenarios	Total CO_2 stored (Gt)		
	2030	2040	2050
A1 - CTP 2040 (EU)	0.142	1.426	3.869
A2 -CTP 2040 (EU+NO)	0.185	1.471	3.915
A3 -CTP 2040 (EU+NO+UK)	0.185	1.471	3.915
B1 - CTP 2040 & Offshore only (EU)	0.139	1.389	3.833
B2 - CTP 2040 & Offshore only (EU+NO+UK)	0.185	1.471	3.915
C1 - CTP 2040 & NZIA targets (EU)	0.128	1.396	3.839
D1 - Fit-for-55 (EU+NO+UK)	0.185	1.044	2.650
D2 - Fit-for-55 & NZIA targets (EU)	0.128	0.969	2.575

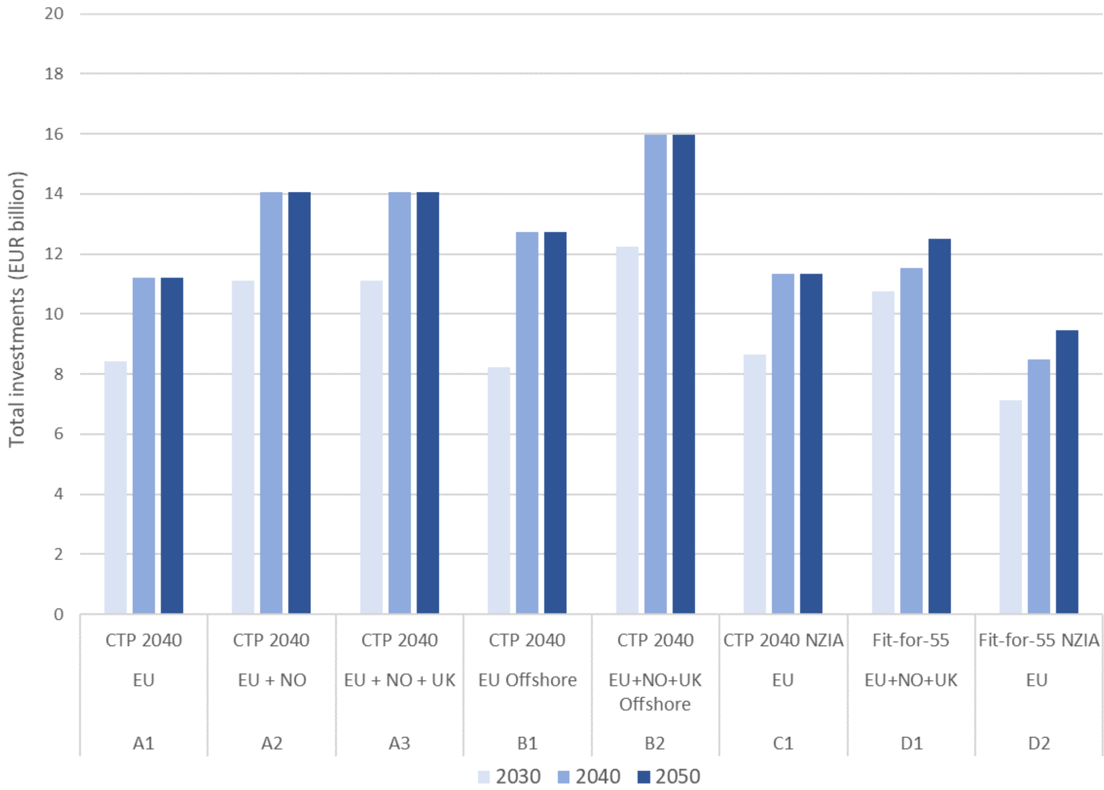
Source: JRC, 2024

The total investment costs range from EUR 9.5 billion for Scenario D2 to EUR 16.0 billion for Scenario B2 (Figure 35). These results are based on medium infrastructure costs (Figure 6). If the low and high estimates of infrastructure costs are taken into account, then the variability of investment costs is much wider (Figure 5) and range between EUR 8.3 billion and EUR 23.1 billion (Figure 36). The results show that the cost-optimal scenarios are those in which certain adjustments to the starting dates of the projects and their capacities have been made (A1, B1, C1 in CTP 2040 group and D2 in Fit-for-55 group), implying that by coordinating and planning the entry into operation of specific projects, overall investment costs for the development of the CO_2 transport network can be reduced.

However, on the other hand, this could lead to an increase in the overall investment costs of CCS implementation and to a lower total amount of CO_2 being stored.

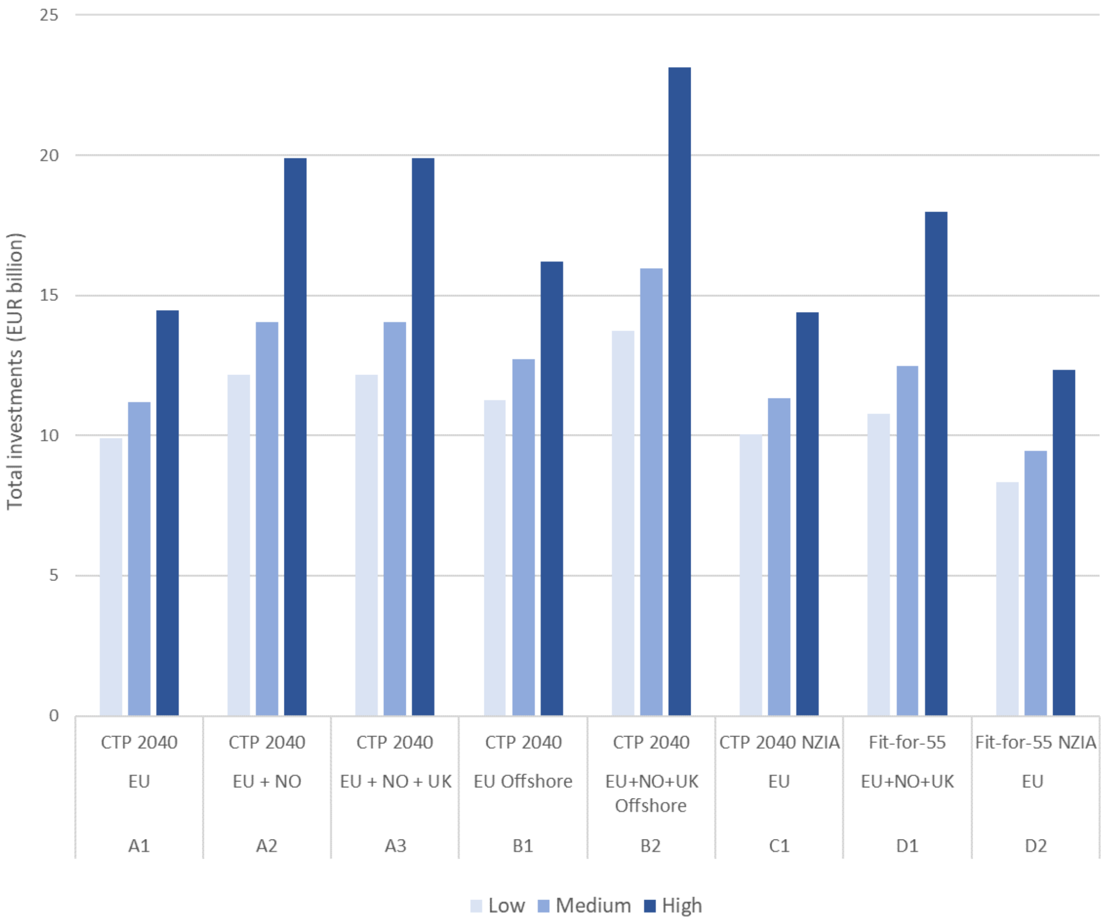
Bearing in mind that the investment costs are based on data from existing CO_2 and natural gas onshore pipeline projects as explained in Section 2.1.3, and considering the recent increase of general infrastructure investment costs, it is reasonable to assume that the higher estimate of the investment costs is closer to reality than the medium estimate.

Figure 35. Total investment costs – medium estimate (EUR billion)



Source: JRC, 2024

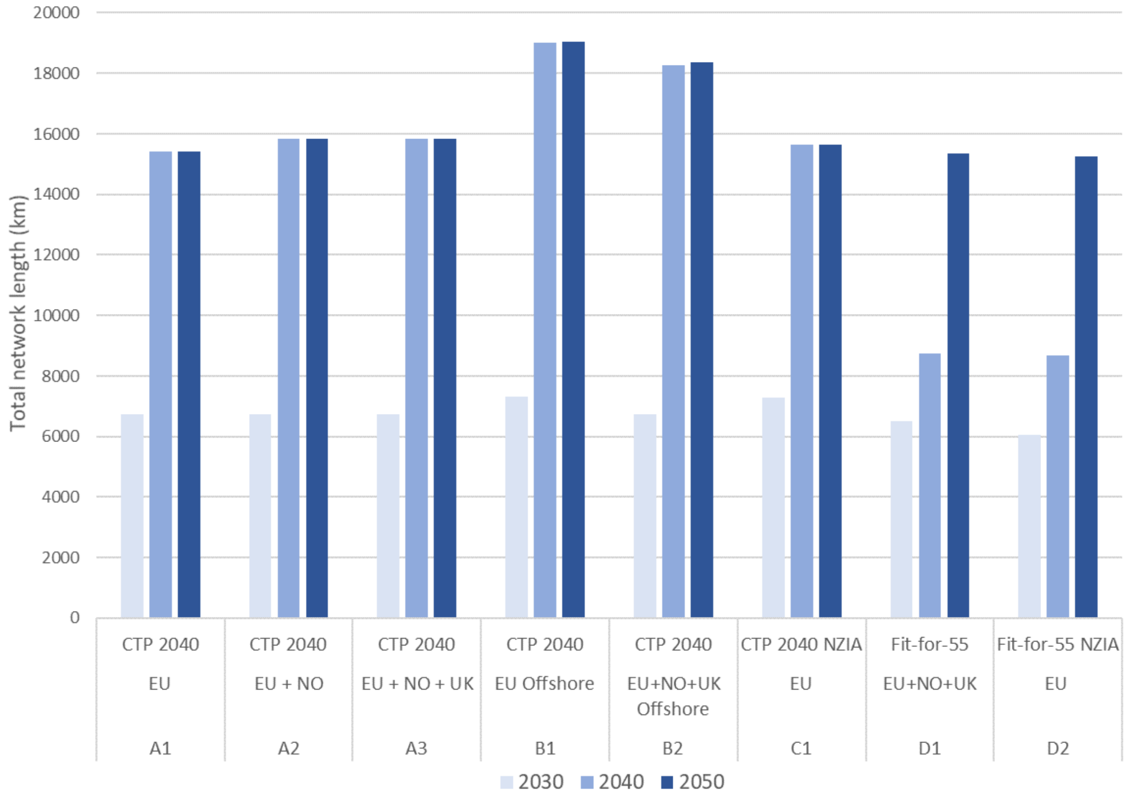
Figure 36. Range of total investments (EUR billion)



Source: JRC, 2024

The network is the longest in scenarios where CO_2 can only be stored offshore (B1 and B2), (EU + NO) and A3 (EU + NO&UK)), while in other scenarios, the difference in length is almost negligible (Figure 37). Average investments costs per kilometre of transport network range from EUR 0.62 m/km (D2) to EUR 0.89 m/km (A2 and A3). If the low and high estimates of infrastructure costs are taken into account, then the variability of average investment costs is much wider and ranges between EUR 0.55 m/km (D2) and EUR 1.26 m/km (A2, A3 and B2).

Figure 37. Total network length (km)



Source: JRC, 2024

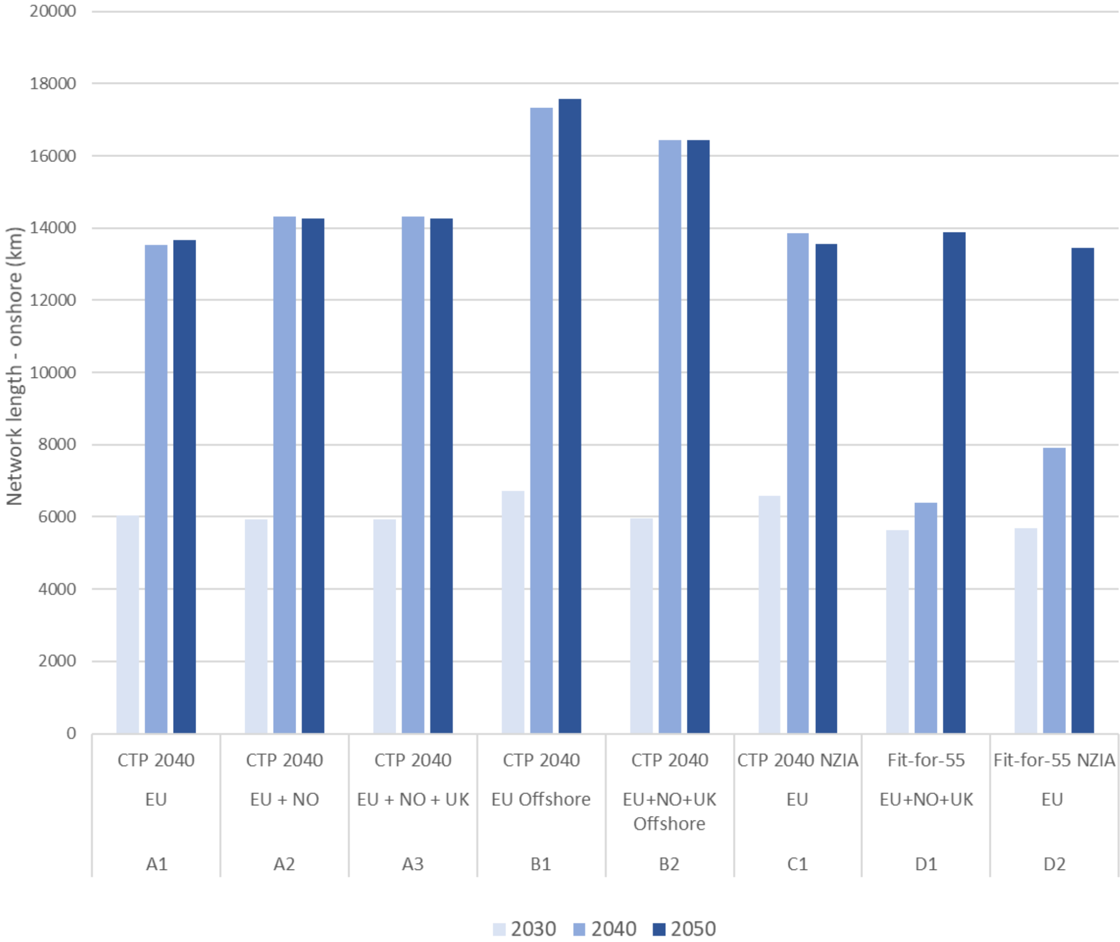
The average flow per pipeline for each scenario is displayed in Table 8, ranging from 11.39 Mtpa (D2) to 16.22 Mtpa (A2 and A3).

Table 8. Average flow of the per pipeline per each scenario

Scenario	Investments (EUR billion)	Average flow (Mtpa)
A1 - CTP 2040 (EU)	11.2	12.4
A2 -CTP 2040 (EU+NO)	14.1	16.2
A3 -CTP 2040 (EU+NO+UK)	14.1	16.2
B1 - CTP 2040 & Offshore only (EU)	12.7	15.9
B2 - CTP 2040 & Offshore only (EU+NO+UK)	16.0	18.1
C1 - CTP 2040 & NZIA targets (EU)	11.4	11.7
D1 - Fit-for-55 (EU+NO+UK)	12.5	14.5
D2 - Fit-for-55 & NZIA targets (EU)	9.5	11.4

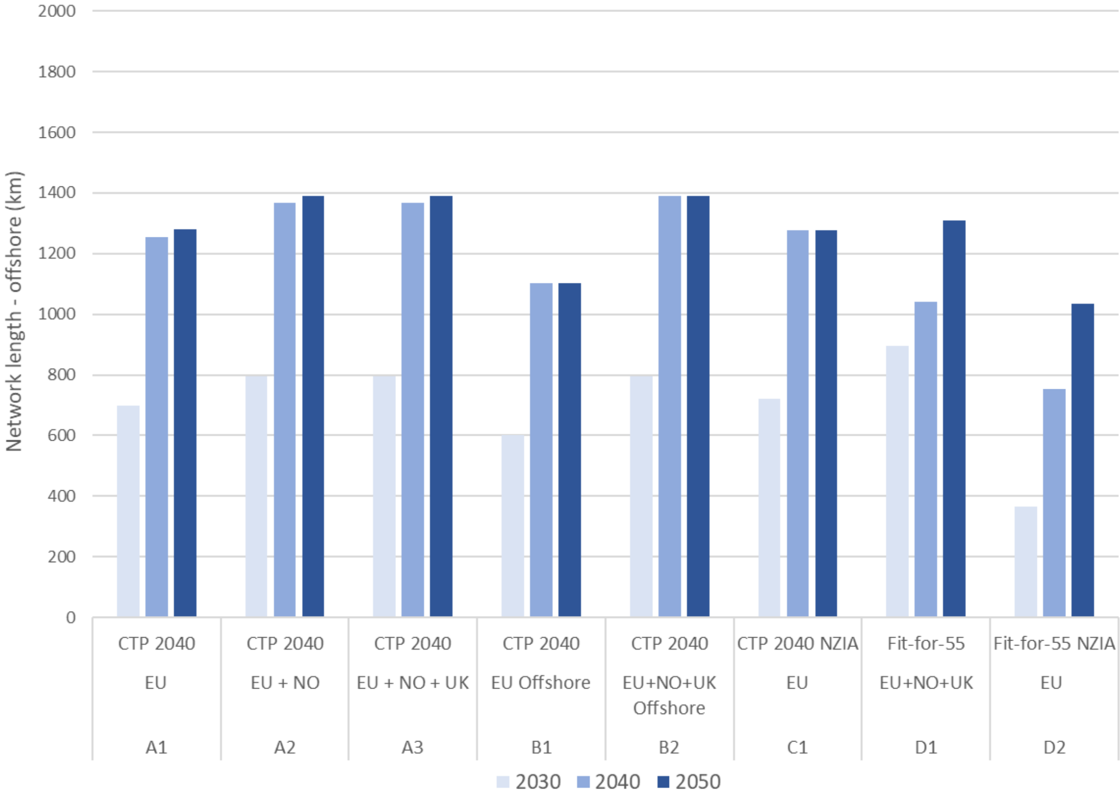
Depending on the scenario, the share of the offshore network in the total length of the transport network ranges between 7% and 9% (Figure 38 and Figure 39). In cases of offshore network routes with small capacity, instead of building long pipeline infrastructure, there is an option to use shipping that could be more suitable, considering its flexibility. However, as explained in Section 2, the analysis does not provide a specific solution regarding the choice between offshore pipeline and shipping.

Figure 38. Network length used – onshore (km)



Source: JRC, 2024

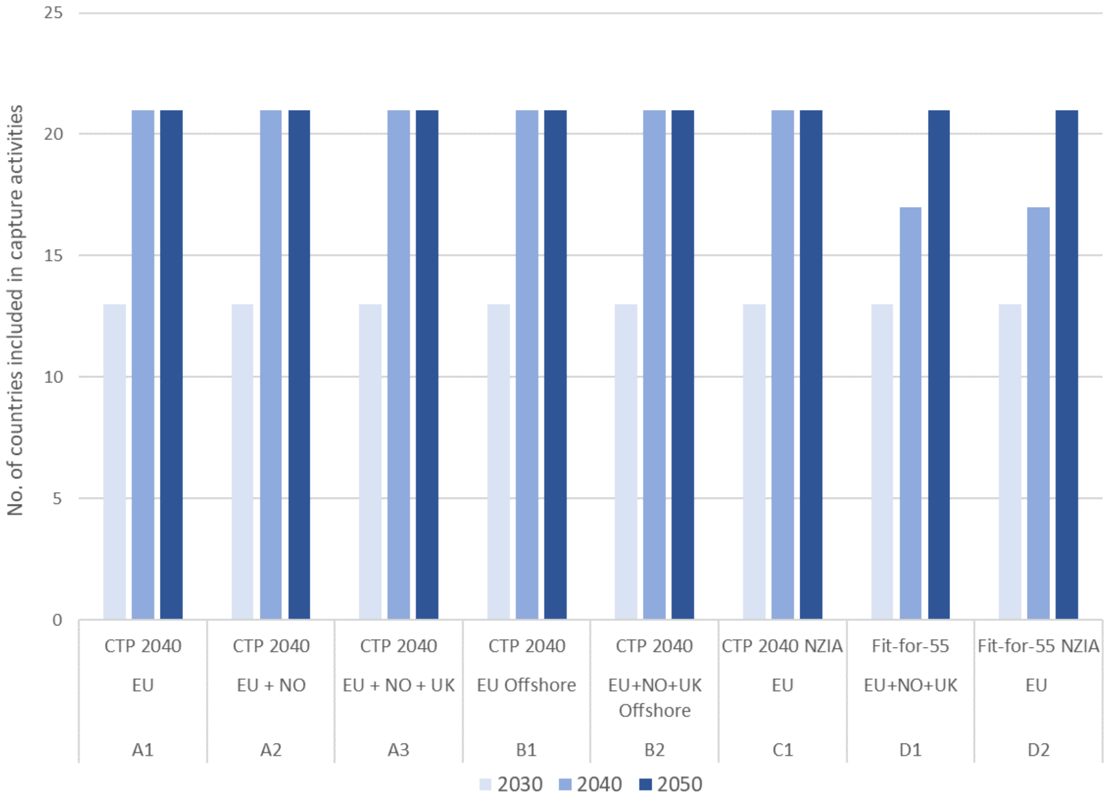
Figure 39. Network length used– offshore (km)



Source: JRC, 2024

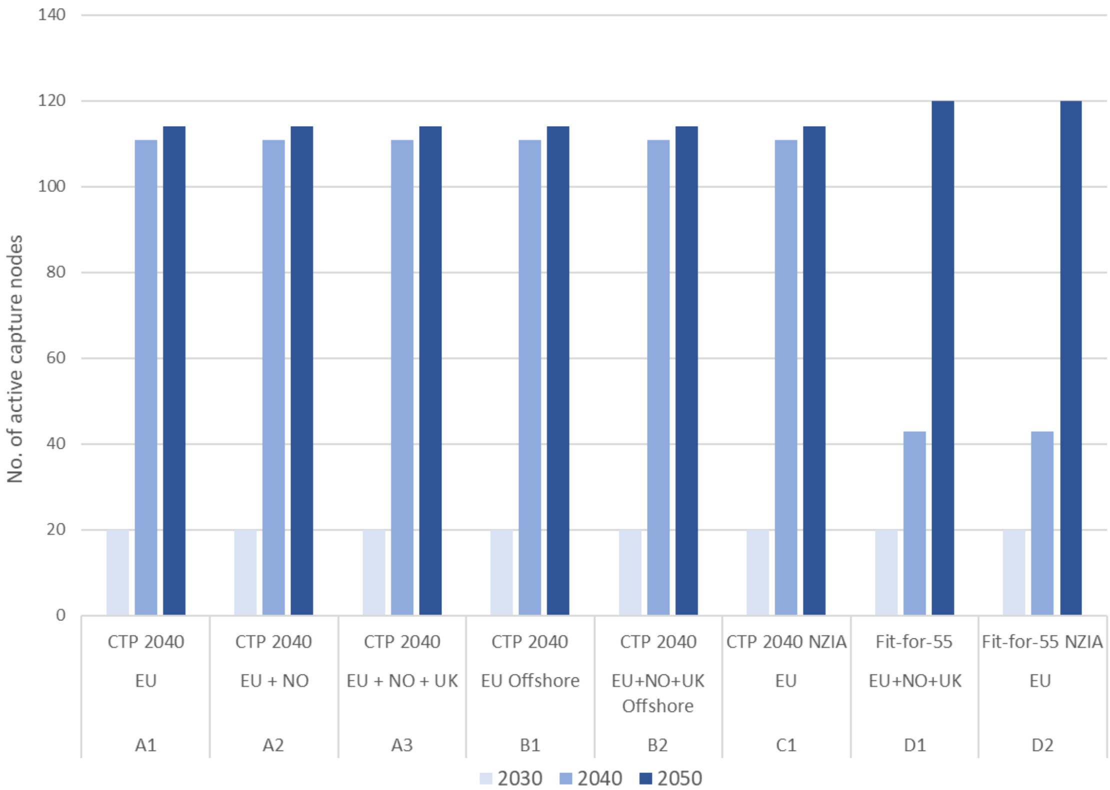
When looking at the number of active capture nodes, it is important to remember that the analysis approaches the optimisation problem from the CO_2 capture side, meaning that in all scenarios considered, the CO_2 capture nodes are fixed and developing at the same pace. In 2030, there are 20 source nodes in 13 countries. In 2040, the number is increasing to 43 (Fit-for-55) and 111 (CTP 2040) source nodes in 17 (Fit-for-55) and 21 (CTP 2040) countries and, in 2050, to 114 (CTP 2040) and 120 (Fit-for-55) source nodes in 21 countries (Figure 40 and Figure 41). If the source node is located in a particular country, it does not necessarily mean that the captured CO_2 is exclusively related to that country. The captured CO_2 amount can also pertain to neighbouring countries if the clustering algorithm has included CO_2 sources from multiple countries.

Figure 40. Number of countries included in capture activities



Source: JRC, 2024

Figure 41. Number of active capture nodes

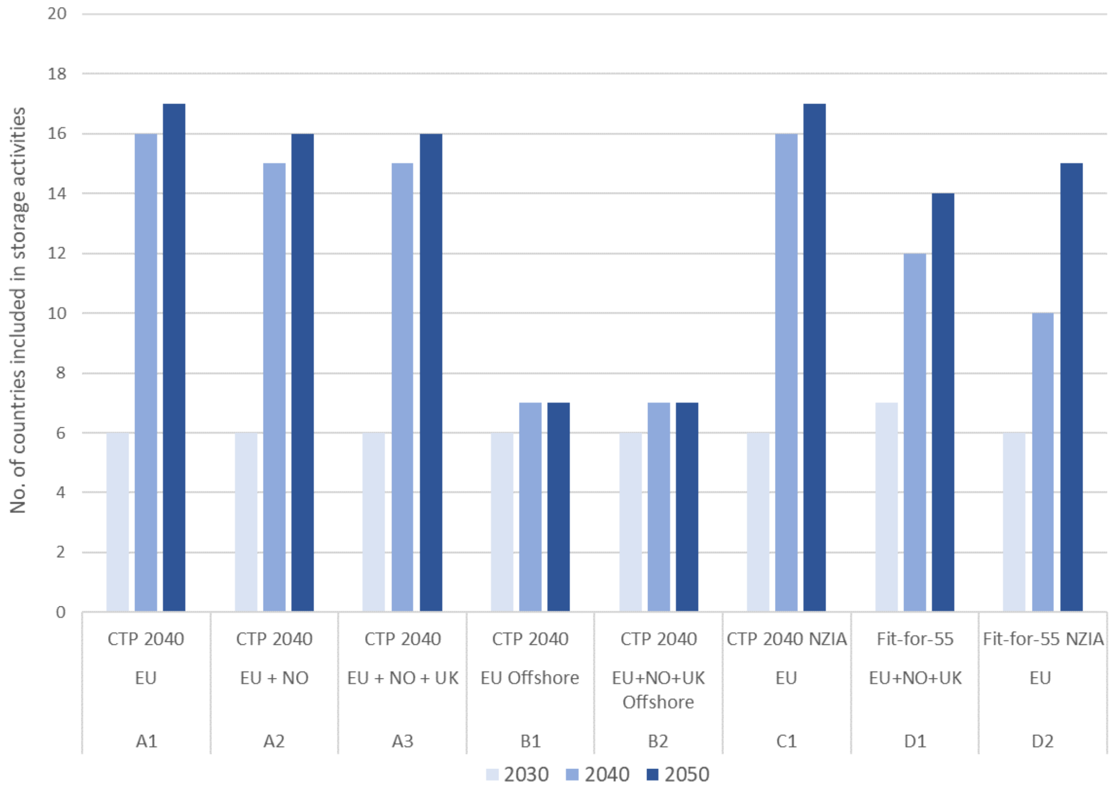


Source: JRC, 2024

The number of active storage nodes and countries involved in CO_2 storage activities is changing depending on the scenario (Figure 42 and Figure 43). In 2030, it is almost the same for all scenarios, as according to the announced projects, the first to become active will be the offshore storage projects. In 2040 and 2050, the numbers of active storage nodes and countries involved are the lowest for the scenarios where only offshore storage locations are available (B1 and B2). However, the number is highest where storage availability is limited to the EU only and where a larger number of smaller capacity storage locations must be used to successfully store the captured CO_2.

The analysis showed that there are no differences in results for A2 and A3 scenarios, since the UK storage locations become available too late (after 2035) to influence the analysis. The results of the analysis indicate that many countries could be involved in storage activities. However, it is important to emphasise that the storage database used within this analysis has significant knowledge gaps, and for a more realistic insight into the distribution of storage locations, a comprehensive assessment should be conducted of storage potential in the EU.

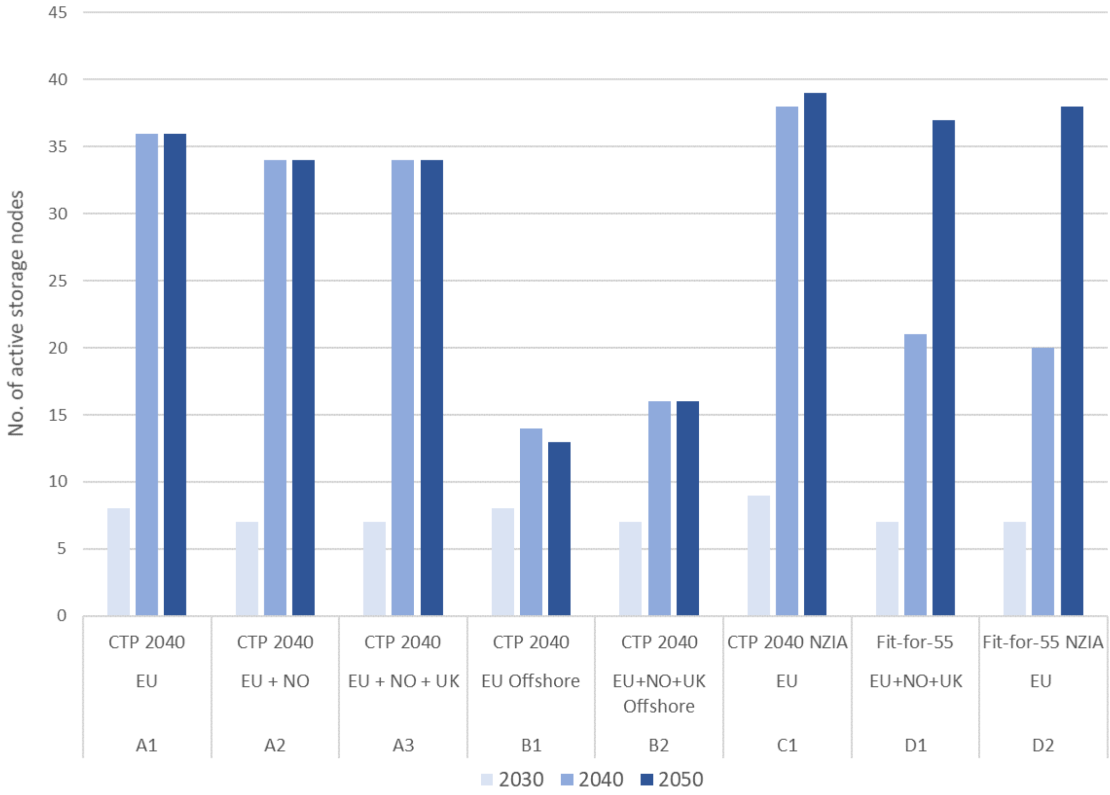
Figure 42. Number of countries included in storage activities



Source: JRC, 2024

All scenarios considered in this study show a fast development of the CO_2 transport network. Since certain areas do not have enough storage capacity initially, the network develops across several countries to connect remote sources and rare active storage nodes. The optimisation model considers the entire observed period and develops the network in a way that can accommodate future CO_2 amounts. However, sometimes it is not possible to build infrastructure that will be active all the time, and there are segments of the network that are no longer needed after some time. This can be observed in the early development of the network when the routes built become unnecessary with the activation of new storage sites closer to the source locations. Such development highlights the need for an integrated approach and planning for the development of CCS at EU level.

Figure 43. Number of active storage nodes

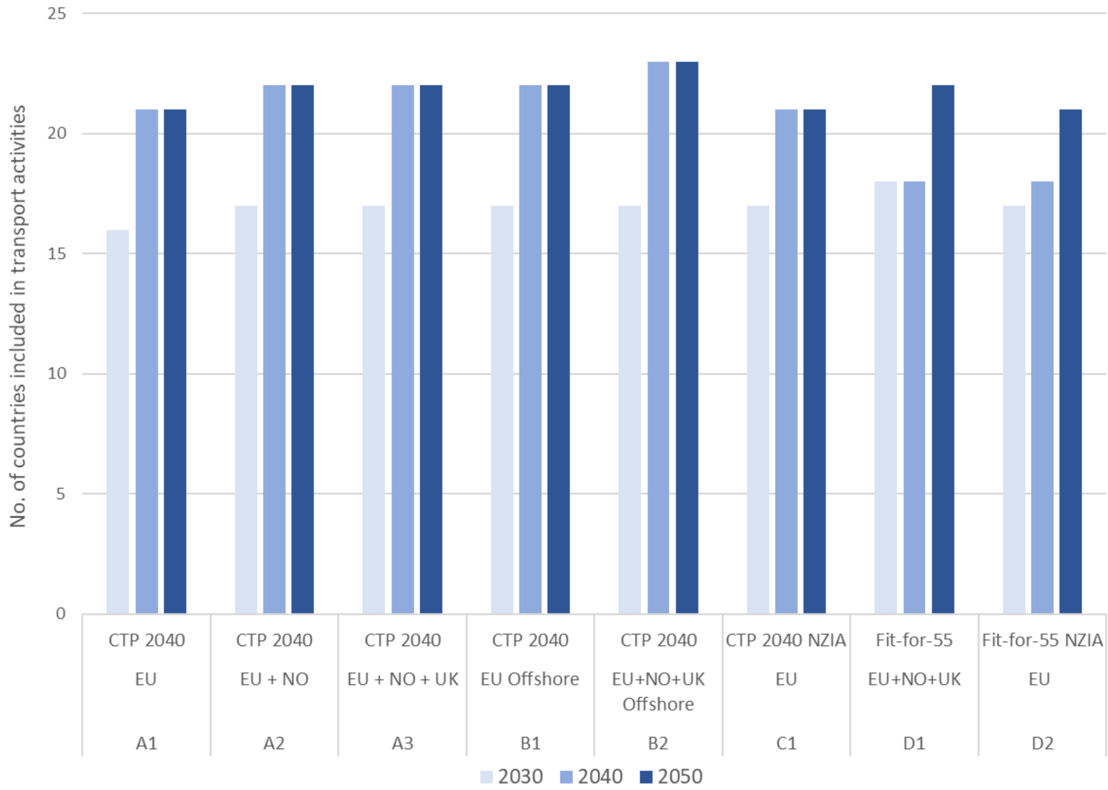


Source: JRC, 2024

The total number of countries through which the transport network passes ranges from 16 in 2030 to 23 in 2050 (Figure 44). It is important to emphasise that the transport network is not fully interconnected. Often, there are large parts of the network that cover a significant number of countries, but there are also regional networks, networks that connect two countries, and a significant number of routes that connect individual capture and storage nodes.

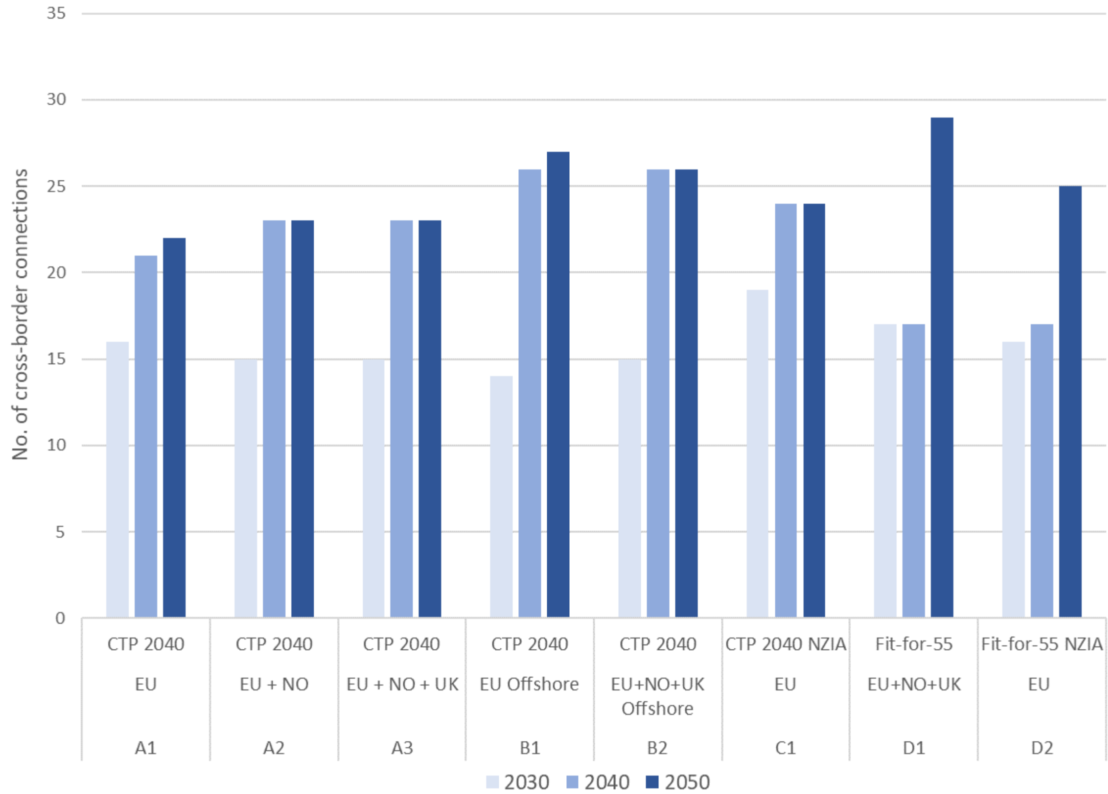
The importance of planning and coordination at EU level is also reflected in the number of cross-border connections, which in 2050 ranges from 22 for A2 to 29 for D1 (Figure 44) .

Figure 44. Number of countries included in transport activities



Source: JRC, 2024

Figure 45. Number of cross-border connections



Source: JRC, 2024

5 Conclusions

The objective of this analysis was to assess the evolution of the extent and the investment requirements of a trans-European CO_2 transport network, based on the latest developments and available information. The analysis covers all EU territory and considers CO_2 storage in Norway and the UK. The time range considered is from 2025 to 2050, with snapshots for 2030 and 2040.

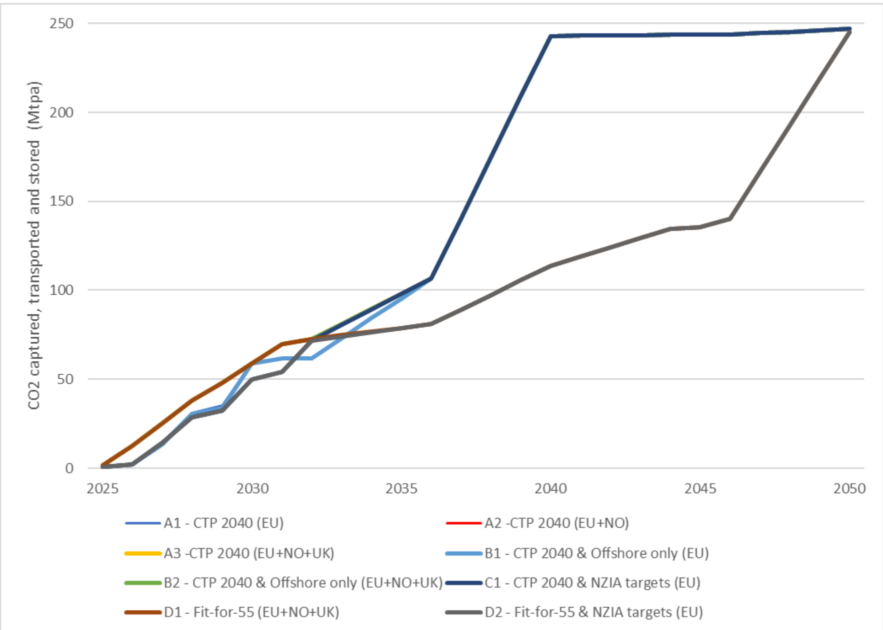
Considering the uncertainties and varying perspectives surrounding the evolution of CO_2 transport networks in Europe, eight scenarios were analysed to explore different potential outcomes. The main division of scenarios is based on two different energy-modelling studies of the Commission: CTP 2040 and Fit-for-55. The first assumes a sharp increase in CO_2 captured between 2030 and 2040, followed by relative stagnation until 2050. The second assumes a milder but constant increase in the period between 2030 and 2050 (Table 1).

The first group of CTP 2040-based scenarios (A1, A2 and A3) focuses on the development of the CO_2 transport network in the EU with separate considerations for storage locations in Norway and the UK. The second group (B1 and B2) examines how the CO_2 transport network would evolve if only offshore storage locations are used to store the CO_2 captured in the EU. What both groups of scenarios have in common is the amount of CO_2 captured each year, which is determined by the announced projects values for the period before 2035 and projected amounts for the later period up to 2050 (Table 6).

Scenario (C1) reflects a storage capacity objective of 50 Mtpa in the EU by 2030, as outlined in the Net-Zero Industry Act proposal (European Commission, 2023). To fit the 50 Mtpa storage capacity in the 2030 objective, certain adjustments to the capture and storage input data had to be made. Because of the adjustments, 75.2 Mt less of CO_2 is stored in the period between 2025 and 2034 in the C1 scenario compared to other scenarios based on the CTP 2040 modelling.

Scenarios D1 and D2 are based on the Fit-for-55 modelling. Scenario D1 is equivalent to scenario A3, and D2 is equivalent to scenario C1. The only difference is that the CO_2 projections considered are based on the Fit-for-55 modelling. The differences in the amounts of CO_2 captured, transported, and stored between scenarios are shown in Figure 46.

Figure 46. Difference in CO_2 captured/transported/stored between scenarios



Source: JRC, 2024

The analysis included 114 (CTP 2040) and 120 (Fit-for-55) source nodes, 95 sink nodes, 19 terminal nodes and 603 (CTP 2040) and 624 (Fit-for-55) potential network connections with a potential total length of about 113 400 km (CTP 2040) and 113 800 km (Fit-for-55). The locations of the nodes and the network of the potential routes are the same in each of the two main groups of scenarios (CTP 2040 and Fit-for-55), as explained in Section 2.

The results of the analysis show that the early adopters, namely CO_2 capture and storage project developers, have a significant impact on the evolution and the extent of the CO_2 transport network. Their characteristics (location, commencement date, capacity) directly influence the locations and capacities of the transport routes. For example, the results of scenarios A2 and A3 are entirely identical. In scenario A2, CO_2 storage is enabled within the EU and Norway, while in scenario A3, storage nodes in the UK are added, but can be used only after 2035 considering the availability of storage locations, as well as the time necessary to address the legal requirements for storing CO_2 captured in the EU in the UK storage locations. Although the storage locations in the UK have significant storage capacity and are close to many CO_2 sources in the EU, the results show that they will not be utilised because the transport infrastructure is already developed and directed mostly towards storage locations in Norway. Taking into account the uncertainty related to storage data, the EU should be open to cooperation outside its borders.

The chosen approach, considering the announced CCS projects, entails the construction of the CO_2 transport network closer to the sites of CCS early adopters. These early adopters primarily consist of high-emitting entities that have taken the initiative in implementing CO_2 capture technologies. By focusing on these early adopters, the initial development of the CO_2 transport infrastructure can effectively support their efforts in reducing emissions.

In reality, the question arises of what needs to be developed first: capture and storage infrastructure or transport infrastructure. Regardless of the response, the CO_2 transport network represents a key enabler for the wider implementation of CCS technologies and to minimise total investment costs, there is a need for cooperation and coordination of CCS infrastructure development at EU level.

Scenarios A1, B1, C1 and D2, without storage capacities outside the EU, resulted in insufficient storage capacity in the early phase of the development of the network. To enable enough storage capacity to solve the optimisation model, the start of operation for certain announced capture projects and their capture capacity development plans had to be advanced by several years. This had to be done for the sake of modelling, but in reality, the gap between the capture demand and storage capacity could be even more significant in the future because the lead times for developing the storage sites are much longer than the time needed for the development of the capture facilities. It is critical to reduce project lead times to increase both capture and storage capacities. The results of scenarios C1 and D1, in which the start dates of capture projects were postponed to a later time, have shown that the EU can meet its needs without Norway, albeit with a reduced amount of total stored CO_2. The fact that there is no sufficient storage in the early phases of CCS development could negatively impact development and implementation plans, and undermine the decarbonisation plans of the EU.

To overcome this problem, it is crucial to accelerate the development of storage capacity. As a first step, it is essential to have an overview of the potential storage capacity and its distribution throughout EU. In this analysis, the main source of data is the CO2StoP project database. Although it represents the most detailed source of CO_2 storage data, it is important to note that it is not entirely up to date and the storage capacities were not assessed for all locations (e.g. storage location and capacities for several countries were not assessed within the project). The dataset was updated with more recent national storage estimates for Norway and Denmark, but there were still a lot of gaps in storage data. The use of more detailed CO_2 storage estimates was considered, available for specific locations as a part of EU-funded projects. However, the combined use of datasets which may vary in terms of level of detail could cause even more discrepancy in the data on storage potential, and consequently even bigger distortions in the infrastructure network. That is the main reason that some countries have very few or almost no storage nodes, with a direct impact on the results of the optimisation.

Furthermore, it is important to emphasise that after 2035, all potential storage locations and capacities identified within the CO2StoP project were available, given that this is an analysis of the optimal network development. It is, however, rather unrealistic, for a variety of reasons, to expect that all these locations will become accessible for CO_2 storage, and there is an even smaller likelihood that actual storage capacities will align with the theoretical capacities estimated within the CO2StoP project. To get a better insight into the extent and the investment requirements of a trans-European CO_2 transport network, it is necessary to have comprehensive and accurate information on storage potential across the continent in the form of a CO_2 storage atlas. Such updated storage data would enhance the understanding of storage capacities and support the development of the most efficient variant of CCS infrastructure (including transport) throughout Europe.

The analysis proved that international coordination and collaboration will be crucial for the successful and cost-optimised development of the CO_2 transport network. Depending on the scenario, the results imply the involvement of up to 18 countries by 2030 and up to 23 countries by 2050. Even if there will be direct connections between individual capture and storage projects within the same country, most of the network infrastructure will be comprised of large transport networks connecting several countries, especially in later stages, transporting tens and even hundreds of megatonnes (Mt) of CO_2. For the deployment of such a CO_2 transport network, it would be highly beneficial to adopt common CO_2 quality standards for transport and storage.

One of the main prerequisites of the optimisation model is that all the CO_2 captured at any given point in time must be stored at that point in time. This requirement can sometimes lead to long transport segments with low transport capacities. The results indicate that at certain points in time, specific regions lack sufficient storage capacities (e.g. southern and eastern Europe). This can be observed in the results for 2030 in almost all scenarios. It happens in the early stages of CCS development when active CO_2 source and sink nodes are rare, and captured CO_2 is transported from remote sources to a small number of active storage locations mostly in the North Sea region.

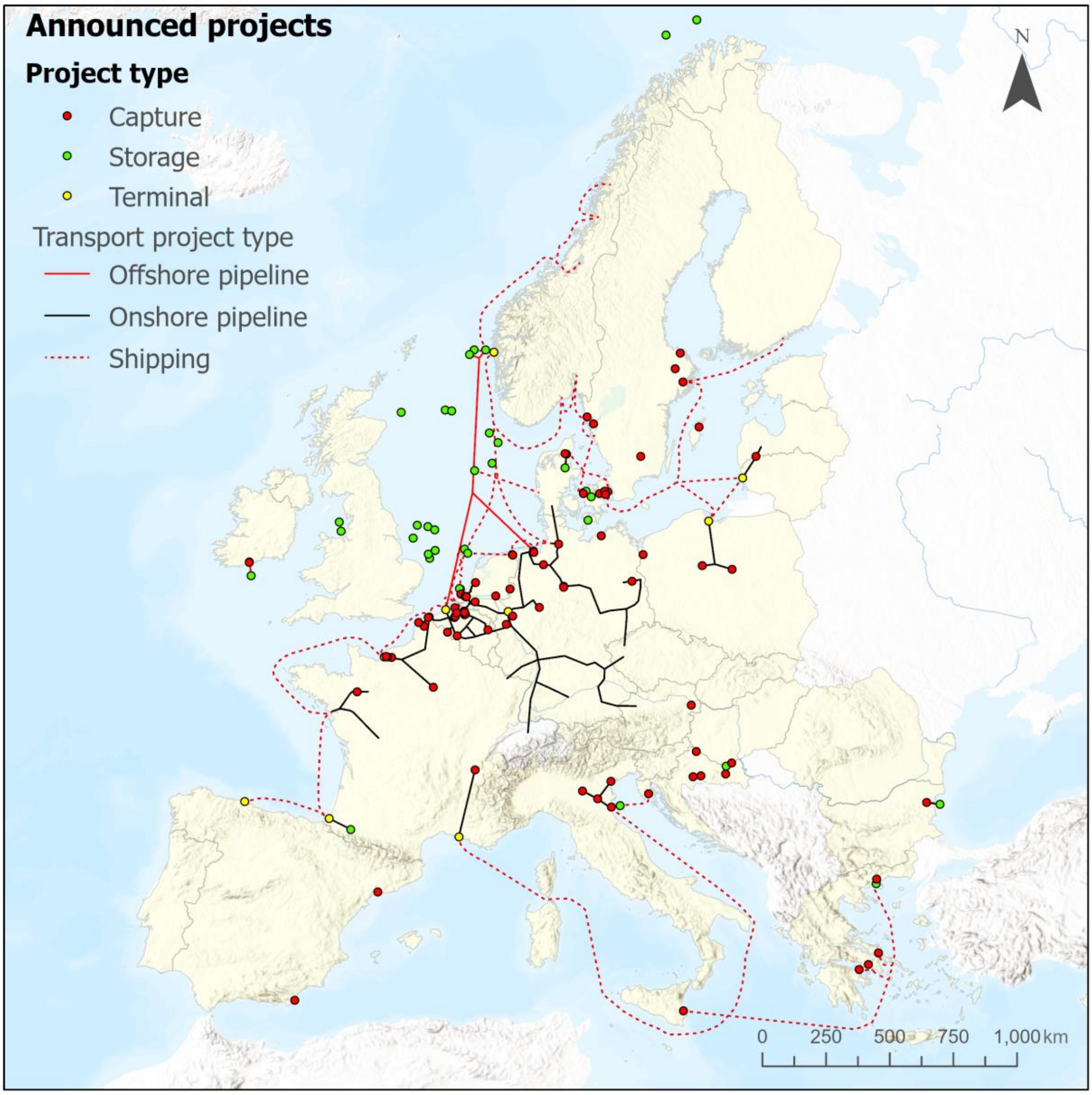
Due to the high investment costs involved in situations like this, other possibilities should be considered. From a planning perspective, it would be beneficial to invest in faster development of storage capacities in those regions, provided that there is a geological precondition for such investment. There are significant knowledge gaps on storage potential in the Mediterranean, but also in the Baltic Sea. On the other hand, in similar situations, the network extends throughout countries which, based on the announced projects or projections, are not capturing CO_2. That could be motivation for project developers to plan the implementation of the CO_2 capture technologies sooner than originally planned. Another possibility is to use alternative and perhaps cheaper modes of transport such as trucks, rail, barges, or, when feasible, shipping until the necessary storage infrastructure is developed. These modes of transportation can be useful in such situations, but their role will be crucial for the transport of captured CO_2 to capture nodes, especially in the early phase of network development.

In the later phases of CO_2 transport network development, the transport of relatively small amounts of captured CO_2 is developed from the islands (e.g. Sardinia and the Balearic Islands) to the mainland. Instead of building long pipeline infrastructure with low capacity, it is an option to use shipping that could be more suitable considering its flexibility, although the best solution would be to find a solution locally, on the island if feasible. The same solutions using alternative modes of transport or finding a more suitable local solution also apply to the potential CO_2 capture sites that are distant from the main CO_2 transport network.

This study does not differentiate between offshore pipelines and shipping. It assumes that the investment costs associated with offshore pipeline transport are equivalent to those of shipping. In addition, the analysis also assumes that constructing a connection (pipeline or shipping) is twice as expensive as building it onshore (Table 2). The choice between offshore pipeline and shipping is quite case-specific and requires a modification of the optimisation model used since the investment costs would always favour shipping, while the operating costs would favour pipeline infrastructure. Since this analysis is focused only on the investment costs, additional data based on a cost analysis of different transport types and modelling parameters are needed, and will be analysed in a future update of this study.

The development of a European CO_2 pipeline infrastructure will be challenging during the early phases of CCS deployment before 2030, and alternative forms of CO_2 transport should be also explored. Based on the announced CO_2 capture, transport and storage projects (Figure 47, Annex 1 and Annex 2), it is realistic to expect that the significant part of the CO_2 transport will take place through alternative forms of transportation to the coast (e.g. via rails, roads or rivers) followed by shipping to offshore storage locations, which make up the majority of the storage capacity. In addition to shorter lead times compared to pipelines construction, shipping offers flexibility, which could be crucial for CO_2 transport in the early phase of the CO_2 transport network development. After 2030, or with further development of CCS and CCU, there could be significant progress in CO_2 transport via pipelines.

Figure 47. Simplified overview of the announced CO_2 capture, transport, terminal and storage projects



Source: JRC, 2024

The intention of this analysis was to gain insights into the extent and evolution of the most effective transport network configuration within the EU that transports projected CO_2 captured amounts to storage sites with the lowest possible investment costs. The results obtained are highly dependent on the underlying assumptions made throughout the analysis, particularly considering the availability of CO_2 storage locations, long-term perspective, uncertainties surrounding CCS deployment rates and timelines, limited availability of reliable data on CO_2 storage sites, and the variability associated with pipeline construction costs.

The results of the analysis represent an optimised CO_2 network, i.e. best-case scenario under the given assumptions. Next to the modelling approach of this study, the network development depends on a variety of additional parameters which are, for example, technical, legal and socioeconomic. Currently, the storage of CO_2 is allowed in most Member States. Some countries only allow offshore storage, while others completely prohibit the storage of CO_2 in their territories. What is certain is that there are large amounts of CO_2 that need to be captured, transported, and stored, and the storage potential still needs to be proven. Therefore, it is necessary to establish international cooperation to have as many options as possible for CO_2 storage.

Recent years have been marked by significant legislative changes in certain countries and a strong development of interest in CCS. The situation with new CCS projects and initiatives is changing almost on a monthly basis, and regular updates of this study are necessary to observe how these new developments will affect the network's evolution.

It would also be interesting to see the effects of UK storage capacities becoming available earlier. Furthermore, this analysis did not cover the captured amounts of CO_2 in Norway and the UK which would have an impact on the availability of their storage capacity for CO_2 captured in the EU. There are also non-EU countries (e.g. Switzerland) which have to use EU CO_2 transport infrastructure for their captured CO_2, as well as EU candidate and potential candidate countries. In addition, there are CCS initiatives that involve more distant countries such as Iceland and the US.

Employing the appropriate regulations, policies, funding and coordination at EU level can lead to a faster, cost-optimised and transparent development of the open-access, multimodal CO_2 transport network in the EU.

References

Bjerketvedt, V.S., A. Tomasgard, and S. Roussanaly, 'Optimal Design and Cost of Ship-Based CO2 Transport under Uncertainties and Fluctuations', *International Journal of Greenhouse Gas Control*, Vol. 103, 2020.

BP, *Statistical Review of World Energy*, 2021.

Carbon Capture Journal, 'First Carbon Storage at Project Greensand', March 8, 2023.

Carbon Limits AS and DNV AS, *Re-Stream - Study on the Reuse of Oil and Gas Infrastructure for Hydrogen and CCS in Europe*, IOGP, Entsog, Concawe, GIE, October 2021.

CCS Cost Reduction Taskforce, *The Potential for Reducing the Costs of CCS in the UK*, 2013.

CO2StoP, *CO2 Storage Potential in Europe - Project No. ENER/C1/154-2011-SI2.611598.*, 2013.

Consoli, C.P., and N. Wildgust, 'Current Status of Global Storage Resources', *Energy Procedia*, Vol. 114, July 2017, pp. 4623–4628.

Element Energy, *CCS Deployment at Dispersed Industrial Sites*, Department for Business Energy and Industrial Strategy (BEIS), 2020.

Enhance Energy Inc., North West Redwater Partnership and Wolf Carbon Solutions Inc., *Alberta Carbon Trunk Line (ACTL) Project - Summary Report*, 2022.

ENTEC, *EU Regulation for the Development of the Market for CO2 Transport and Storage*, May 15, 2023.

European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions - A Green Deal Industrial Plan for the Net-Zero Age, COM(2023) 62*, February 1, 2023.

European Commission, *IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for All A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy*, 2018.

European Commission, *Net Zero Industry Act*, March 16, 2023.

Eurostat, *Greenhouse Gas Emissions by Source Sector*, 2022.

EUTS, *ETS Registry Data*, May 2022.

Global CCS Institute, *Global Storage Portofolio - A Global Assessment of the Geological CO2 Storage Resource Potential*, Global Carbon Capture and Storage Institute Ltd (Global CCS Institute), 2016.

IEAGHG, *CO2 Pipeline Infrastructure*, 2014.

International Energy Agency, *World Energy Outlook 2019*, *World Energy Outlook*, OECD, 2019.

International Energy Agency, *World Energy Outlook 2022*, *World Energy Outlook*, OECD, 2022.

International Energy Agency (IEA), *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach - 2023 Update*, September 2023.

Knoppe, M.M.J., A. Ramirez, and A.P.C. Faaij, 'A State-of-the-Art Review of Techno-Economic Models Predicting the Costs of CO2 Pipeline Transport', *International Journal of Greenhouse Gas Control*, Vol. 16, 2013.

Langenbrunner, B., G. Aitken, and R. Rozansky, *Europe Gas Tracker Report 2023*, 2023.

Lyng Anthonsen, K., and N.P. Christensen, *EU Geological CO_2 Storage Summary*, Geological Survey of Denmark and Greenland, Clean Air Task Force, October 2021.

Mikunda, T., J. van Deurzen, A. Seebregts, K. Kerssemakers, M. Tetteroo, and L. Buit, 'Towards a CO2 Infrastructure in North-Western Europe: Legalities, Costs and Organizational Aspects', *Energy Procedia*, Vol. 4, 2011.

Morbee, J., J. Serpa, and E. Tzimas, 'Optimised Deployment of a European CO2 Transport Network', *International Journal of Greenhouse Gas Control*, Vol. 7, 2012, pp. 48–61.

National Energy Technology Laboratory (NETL), *Carbon Dioxide Transport and Storage Costs in NETL Studies - Quality Guidelines for Energy System Studies*, 2019.

Norwegian Petroleum Directorate, *CO2 Storage Atlases*, 2019.

Pale Blue Dot, *Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource - A Summary of Results from the Strategic UK CO2 Storage Appraisal Project*, April 1, 2016.

Poulsen, N., S. Holloway, F. Neele, N.A. Smith, and K. Kirk, *CO2StoP Executive Summary*, The Geological Survey of Denmark and Greenland, March 2014.

Poulsen, N., S. Holloway, F. Neele, N.A. Smith, and K. Kirk, *CO2StoP Final Report*, The Geological Survey of Denmark and Greenland, March 2014.

Serpa, J., J. Morbee, and E. Tzimas, *Technical and Economic Characteristics of a CO2 Transmission Pipeline Infrastructure*, 2011.

Smith, E., J. Morris, H. Kheshgi, G. Teletzke, H. Herzog, and S. Paltsev, 'The Cost of CO2 Transport and Storage in Global Integrated Assessment Modelling', *International Journal of Greenhouse Gas Control*, Vol. 109, 2021.

US National Petroleum Council, *A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage*, 2021.

Vangklide-Pedersen, T., *EU GeoCapacity Assessing European Capacity for Geological Storage of Carbon Dioxide*, Final report, 2009.

ZEP, *The Cost of CO2 Transport*, July 15, 2011.

Zimmerman, S., B. Langenbrunner, and G. Aitken, *Europe Gas Tracker Report 2022*, 2022.

List of abbreviations and definitions

Abbreviations	Definitions
BDAP	Big Data Analytics Platform
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CDR	Carbon Dioxide Removal
COP	Conference of Parties
CTP	Climate Target Plan
DAC	Direct Air Capture
EC	European Commission
EIGL	Energy and Industry Geography Lab
ETS	Emission Trading System
EU	European Union
Gt	Gigatonnes
IF	Innovation Fund
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MS	Member State
Mtpa	Megatonnes per Annum
NZE	Net Zero Emissions
NZIA	Net Zero Industry Act
PCI	Project of Common Interest

Abbreviations	Definitions
PMI	Project of Mutual Interest
R/P	Reserve to Production ratio
UK	United Kingdom
US	United States
ZEP	Zero Emission Platform

List of figures

List of tables

Annex 1. List of announced CO_2 capture, terminal and storage projects

Country	Project name	Project type	Capacity (Mtpa)								References				
			2025	2026	2027	2028	2029	2030	2031	2032					
Austria	Carbon2ProductAustria - C2PAT (Mannersdorf)	Capture	0.00	0.01	0.01	0.01	0.01	0.70	0.70	0.70	Link	Link	Link		
Belgium	H2BE (Ghent)	Capture	0.00	0.00	2.00	2.00	2.00	2.00	2.00	2.00	Link	Link			
Belgium	Antwerp@C CO2 export Hub	CO2 terminal (hub)	-	-	-	-	-	-	-	-	Link				
Belgium	Kairos@C (BASF Antwerp CCS)	Capture	0.00	0.00	1.40	1.40	1.40	1.40	1.40	1.40	Link	Link	Link	Link	
Belgium	Borealis Antwerp CCS*	Capture	0.00	0.00	0.47	1.40	2.53	2.53	2.53	2.53	Link	Link			
Belgium	Exxonmobil Antwerp Refinery CCS*	Capture	0.00	0.00	0.47	1.40	2.53	2.53	2.53	2.53	Link	Link			
Belgium	Ineos Antwerp CCS*	Capture	0.00	0.00	0.47	1.40	2.53	2.53	2.53	2.53	Link	Link			
Belgium	ArcelorMittal Steelanol Ghent	Capture	0.11	0.23	0.23	0.23	0.23	0.23	0.23	0.23	Link	Link	Link		
Belgium	LEILAC-1 (Lixhe)	Capture	0.03	0.03	0.03	0.03	0.03	0.03	0.03	1.20	Link	Link	Link		
Belgium	North-CCU-Hub (Rodenhuizen peninsula)	Capture	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.07	Link				
Belgium	Power-to-methanol Antwerp BV (INOVYN site in Lillo)	Capture	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Link				
Belgium	Anthemis (Heidelberg Cement Antoing)	Capture	0.00	0.00	0.00	0.00	0.80	0.80	0.80	0.80	Link	Link			
Belgium	GO4ZERO (Holcim Obourg)	Capture	0.00	0.00	0.00	1.30	1.30	1.30	1.30	1.30	Link	Link			
Belgium	Ghent Carbon Hub	CO2 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
Belgium	Zeebrugge CO2 collection Hub	CO2 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
Bulgaria	ANRAV-CCUS	Capture	0.00	0.00	0.00	0.60	0.78	0.78	0.78	0.78	Link	Link			
Bulgaria	ANRAV-CCUS (Galata field)	Offshore storage	0.00	0.00	0.00	0.60	0.78	0.78	0.78	0.78	Link	Link			
Croatia	Petrokemija Kutina	Capture	0.00	0.00	0.19	0.19	0.19	0.19	0.19	0.19	Link				
Croatia	Sisak biorefinery	Capture	0.00	0.00	0.06	0.06	0.06	0.06	0.06	0.06	Link	Link			
Croatia	Draskovec Geothermal Plant with CO2 Re-injection	Capture	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Link				
Croatia	Draskovec Geothermal Plant with CO2 Re-injection	Onshore storage	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Link				
Croatia	CO2NTESSA (Nexe cement factory)	Capture	0.00	0.00	0.00	0.00	0.70	0.70	0.70	0.70	Link	Link			
Croatia	Geothermal CCS Croatia (Bockovci site)	Onshore storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	Link				
Croatia	KOdeCO Koromacno	Capture	0.00	0.00	0.00	0.37	0.37	0.37	0.37	0.37	Link	Link			
Denmark	Aalborg Portland	Capture	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.40	Link	Link	Link	Link	
Denmark	Greensand	Offshore storage	0.00	1.50	1.50	1.50	5.00	8.00	8.00	8.00	Link	Link	Link	Link	Link
Denmark	Bifrost	Offshore storage	0.00	0.00	0.00	3.00	3.00	3.00	3.00	3.00	Link	Link	Link		
Denmark	Stenlille demo project	Onshore storage	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	Link	Link	Link	Link	
Denmark	HOFOR biomass*	Capture	0.00	0.00	0.00	0.00	0.00	0.54	0.54	0.54	Link				
Denmark	ARGO waste-to-energy plant*	Capture	0.00	0.00	0.00	0.00	0.00	0.54	0.54	0.54	Link	Link			
Denmark	BIOFOS Carbon Capture Project*	Capture	0.00	0.00	0.00	0.00	0.00	0.54	0.54	0.54	Link	Link	Link		
Denmark	Copenhill (Amager Bakke)	Capture	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	Link	Link	Link	Link	Link
Denmark	Vestforbraending WtE	Capture	0.00	0.00	0.00	0.00	0.00	0.45	0.45	0.45	Link	Link	Link	Link	Link
Denmark	Avedøre Power Station	Capture	0.00	0.23	0.23	0.23	0.23	0.23	0.23	0.23	Link	Link	Link	Link	Link
Denmark	Kalundborg refinery (Aesnes)	Capture	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	Link	Link	Link		
Denmark	Port of Aalborg terminal	CO2 terminal (hub)	-	-	-	-	-	-	-	-	Link				

Denmark	Port of Kalundborg terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link				
Denmark	Trelleborg (Norne)	Onshore storage	0.00	0.00	1.15	1.15	1.15	10.00	10.00	10.00	Link				
Denmark	Fyrkat (Norne)	Onshore storage	0.00	0.00	1.15	1.15	1.15	8.00	8.00	8.00	Link	Link			
Denmark	Ruby storage project	Onshore storage	0.00	0.00	1.00	1.00	1.00	7.00	7.00	7.00	Link				
France	Bayonne terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
France	Lacq storage site	Onshore storage	0.00	0.00	0.00	0.00	0.00	0.00	2.50	2.50	Link	Link	Link		
France	3D ProjectDMX Demonstration in Dunkirk	Capture	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Link	Link	Link		
France	K6 Program (Lumbres cement plant)	Capture	0.00	0.00	0.00	0.80	0.80	0.80	0.80	0.80	Link				
France	CalCC	Capture	0.00	0.00	0.00	0.58	0.58	0.58	0.58	0.58	Link	Link			
France	Dartagnan (Dunkirk Hub)	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
France	Le Havre terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link	Link		
France	Port Jérôme CO2 Capture Plant	Capture	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	Link				
France	Air Liquide Normandy CCS	Capture	0.00	0.00	0.00	0.00	0.00	0.65	0.65	0.65	Link	Link			
France	Grandpuits biorefinery	Capture	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	Link	Link			
France	Hynovi project (Montalieu-Vercieu cement plant)	Capture	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	Link				
France	Fos-Marseille Hub	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
France	Grand Ouest CO2 (GOCO$_2$)	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
France	Holcim Saint-Pierre-la-Cour	Capture	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	Link	Link			
Germany	LEILAC 2 project (Zementwerk Hannover)	Capture	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	Link	Link			
Germany	Wilhelmshaven (CO2nnectNow)	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
Germany	C2B: Carbon2Business (Lagerdorf)	Capture	0.00	0.00	0.00	0.76	1.30	1.30	1.30	1.30	Link				
Germany	BlueHyNow	Capture	0.00	1.30	1.30	1.30	1.30	1.30	1.30	1.30	Link	Link			
Germany	H2GE Rostock	Capture	0.00	0.00	0.00	0.00	2.00	2.00	2.00	2.00	Link	Link			
Germany	EVEREST (Flandersbach lime plant in Wülfrath)	Capture	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	Link				
Germany	Niederaussem Pilot Plant	Capture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Link	Link			
Germany	H2morrow	Capture	0.00	0.00	1.90	1.90	1.90	1.90	1.90	1.90	Link	Link			
Germany	Carbon Clean CEMEX	Capture	0.00	0.11	0.11	0.11	0.11	0.11	0.11	0.11	Link	Link			
Germany	LafargeHolcim Hover (Hannover)	Capture	0.18	0.80	0.80	0.80	0.80	0.80	0.80	0.80	Link				
Germany	Arcelor Mittal (Bremen)	Capture	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	Link				
Germany	GeZero (Zementwerk Geseke)	Capture	0.00	0.00	0.00	0.00	0.70	0.70	0.70	0.70	Link				
Greece	Prinos Sigma Plant	Capture	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Link				
Greece	Prinos CO2 storage	Offshore storage	0.00	0.10	0.50	2.50	2.50	2.50	2.50	2.50	Link	Link	Link	Link	Link
Greece	Ifestos Carbon Capture (Kamati plant)	Capture	0.00	0.00	0.00	0.00	0.00	1.90	1.90	1.90	Link				
Greece	Milaki Plant	Capture	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	Link				
Greece	Motor Oil Hellas (Iris)	Capture	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	Link	Link			
Hungary	Beremend cement factory	Capture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	Link				
Ireland	Aghada CCGT	Capture	0.00	0.00	0.00	0.83	0.83	0.83	0.83	0.83	Link	Link	Link		
Ireland	Irving refinery	Capture	0.00	0.00	0.00	0.83	0.83	0.83	0.83	0.83	Link	Link	Link		
Ireland	Whitegate CCGT	Capture	0.00	0.00	0.00	0.83	0.83	0.83	0.83	0.83	Link	Link	Link		
Ireland	Ervia Cork CCS	Offshore storage	0.00	0.00	0.00	2.50	2.50	2.50	2.50	2.50	Link	Link			
Italy	ENI Casalborsetti (Ravenna) power plant*	Capture	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	Link				

Italy	ENI Ferrara power plant *	Capture	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	Link				
Italy	ENI Mantova power plant*	Capture	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	Link				
Italy	ENI Venice bio-refinery Porto Marghera*	Capture	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	Link				
Italy	Ravenna storage	Offshore storage	0.00	0.00	0.00	4.00	4.00	4.00	4.00	4.00	Link	Link	Link		
Italy	Ravenna Hub	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link	Link		
Italy	Augusta C2	Capture	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	Link				
Italy	Buzzi Unicem Augusta buffer storage	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link				
Lithuania	Klaipeda terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link				
Lithuania	Orlen Lietuva	Capture	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	Link				
Netherlands	H-Vision (Onyx)	Capture	0.00	0.00	1.30	1.30	1.30	1.30	1.30	2.70	Link	Link			
Netherlands	H2M Magnum	Capture	0.00	0.00	0.00	1.75	1.75	1.75	1.75	1.75	Link	Link	Link	Link	
Netherlands	Vlissingen Cryocap FG	Capture	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	Link	Link			
Netherlands	Air Products Refinery Rotterdam CCS *	Capture	0.00	0.63	0.63	0.63	0.63	0.63	0.63	0.63	Link	Link	Link		
Netherlands	Shell Refinery Rotterdam CCS*	Capture	0.00	0.63	0.63	0.63	0.63	0.63	0.63	0.63	Link	Link	Link		
Netherlands	Air Liquide Refinery Rotterdam CCS*	Capture	0.00	0.63	0.63	0.63	0.63	0.63	0.63	0.63	Link	Link	Link		
Netherlands	ExxonMobil Benelux Refinery CCS*	Capture	0.00	0.63	0.63	0.63	0.63	0.63	0.63	0.63	Link	Link	Link		
Netherlands	Shell heavy residue gasification	Capture	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	Link				
Netherlands	Porthos 1	Offshore storage	0.00	1.25	1.25	1.25	1.25	1.25	1.25	1.25	Link	Link	Link		
Netherlands	Porthos 2	Offshore storage	0.00	1.25	1.25	1.25	1.25	1.25	1.25	1.25	Link	Link	Link		
Netherlands	AVR-Duiven	Capture	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	Link	Link			
Netherlands	Twence Waste-to-Energy	Capture	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	Link	Link	Link	Link	
Netherlands	L10 Carbon Capture and Storage	Offshore storage	0.00	0.00	5.00	5.00	5.00	5.00	5.00	5.00	Link	Link	Link		
Netherlands	AEB Amsterdam	Capture	0.00	0.44	0.44	0.44	0.44	0.44	0.44	0.44	Link	Link			
Netherlands	Yara Sluiskil	Capture	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	Link	Link	Link		
Netherlands	Aramis	Offshore storage	0.00	0.00	0.00	5.00	5.00	5.00	8.00	8.00	Link	Link	Link	Link	Link
Netherlands	CO2Next project	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link	Link	Link	
Netherlands	Eemshaven Hub	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
Netherlands	RWE (Amer power plant)	Capture	0.00	0.00	0.00	0.00	0.00	0.00	5.50	5.50	Link				
Netherlands	RWE (Eemshaven)	Capture	0.00	0.00	0.00	0.00	0.00	0.00	5.50	5.50	Link				
Norway	Smeaheia	Offshore storage	0.00	0.00	0.00	20.00	20.00	20.00	20.00	20.00	Link	Link			
Norway	Luna	Offshore storage	0.00	0.00	0.00	0.00	5.00	5.00	5.00	5.00	Link				
Norway	Snohvit	Offshore storage	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	Link	Link			
Norway	Sleipner	Offshore storage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Link	Link	Link		
Norway	Polaris Carbon Storage Project	Offshore storage	0.00	0.00	0.00	0.00	0.00	3.00	3.00	3.00	Link	Link	Link		
Norway	Northern Lights	Offshore storage	1.50	1.50	5.20	5.20	5.20	5.20	5.20	5.20	Link	Link	Link	Link	Link
Norway	Øygarden terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link	Link		
Norway	Poseidon	Offshore storage	0.00	0.00	0.00	0.00	0.00	5.00	5.00	5.00	Link				
Norway	Havstjerne	Offshore storage	0.00	0.00	7.00	7.00	7.00	7.00	7.00	7.00	Link	Link			
Norway	Trudvang	Offshore storage	0.00	0.00	0.00	0.00	0.00	9.00	9.00	9.00	Link				
Poland	Gdansk Hub	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link				
Poland	GO4ECOPLANET: KUJAWY	Capture	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	Link	Link			

Poland	Plock ORLEN refinery	Capture	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	Link				
Poland	PGE (Szczecin)	Capture	0.00	0.00	0.00	0.12	0.12	0.12	0.12	0.12	Link				
Spain	CCU Lighthouse Carboneras	Capture	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	Link	Link			
Spain	ECOPLANTA (Tarragona)	Capture	0.00	0.00	0.34	0.34	0.34	0.34	0.34	0.34	Link				
Spain	Gijon terminal	C02 terminal (hub)	-	-	-	-	-	-	-	-	Link	Link			
Sweden	Beccs Stockholm	Capture	0.00	0.20	0.78	0.78	0.78	0.78	0.78	0.78	Link				
Sweden	AIR	Capture	0.00	0.00	0.41	0.41	0.41	0.41	0.41	0.41	Link	Link	Link		
Sweden	Vattenfall Uppsala	Capture	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	Link				
Sweden	Preem CCS (Lysekil refinery)	Capture	0.00	0.50	0.50	0.50	0.50	1.50	1.50	1.50	Link	Link			
Sweden	HySkies (Forsmark)	Capture	0.00	0.00	0.00	0.21	0.21	0.21	0.21	0.21	Link				
Sweden	Cementa Slite Plant	Capture	0.00	0.00	0.00	0.00	0.00	1.80	1.80	1.80	Link	Link			
Sweden	Växjö Energi CHP CCS (Sandviksverket)	Capture	0.00	0.00	0.18	0.18	0.18	0.18	0.18	0.18	Link				
United Kingdom	Bacton Thames Net Zero Initiative	Offshore storage	0.00	0.00	10.00	10.00	10.00	10.00	10.00	10.00	Link	Link	Link	Link	Link
United Kingdom	Acorn storage site	Offshore storage	0.00	0.00	1.00	1.00	1.00	5.00	5.00	5.00	Link	Link	Link	Link	
United Kingdom	HyNet North West storage project	Offshore storage	0.00	0.00	4.50	4.50	4.50	10.00	10.00	10.00	Link	Link	Link	Link	Link
United Kingdom	Nothern Endurance Partnership	Offshore storage	0.00	5.00	5.00	5.00	15.00	15.00	15.00	15.00	Link	Link	Link	Link	Link
United Kingdom	Viking CCS	Offshore storage	0.00	0.00	3.60	3.60	3.60	10.00	10.00	10.00	Link	Link	Link	Link	
United Kingdom	Orion	Offshore storage	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	Link	Link			
United Kingdom	Poseidon (UK)	Offshore storage	0.00	0.00	0.00	0.00	0.00	1.50	1.50	1.50	Link	Link			
United Kingdom	Spirit Morecambe	Offshore storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Link	Link			

*estimated since capacities on a facility level were not available

Annex 2. List of announced CO_2 transport projects

Country	Project name	Project type	References			
Belgium	Fluxys CO2 network	Onshore pipeline	Link			
Belgium, Netherlands	Carbon Connect Delta	Onshore pipeline	Link	Link	Link	
Belgium, Germany, Norway	EU2NSEA	Offshore pipeline	Link			
Bulgaria	Anrav	Onshore pipeline/Offshore pipeline	Link	Link		
Croatia, Hungary	Geothermal CCS Croatia	Onshore pipeline	Link	Link		
Denmark	Bifrost	Shipping/Offshore pipeline	Link			
Denmark	Norne	Onshore pipeline/Shipping	Link			
Denmark	Greensand	Shipping	Link	Link	Link	Link
Germany	German Carbon Transport Grid	Onshore pipeline	Link	Link		
Germany, Switzerland	WH2V	Onshore pipeline	Link			
Greece	Prinos CO2 storage	Shipping	Link	Link	Link	
France	Dunkirk	Onshore pipeline	Link			
France	Grand Ouest CO2 (GOCO$_2$) transport	Onshore pipeline/Shipping	Link	Link		
France	Pycasso	Onshore pipeline/Shipping	Link	Link		
France	GRTgaz	Onshore pipeline	Link			
Ireland	Cork CCS pipeline	Offshore pipeline	Link	Link		
Italy	Ravenna	Onshore pipeline/Shipping	Link	Link	Link	Link
Italy, Greece	Augusta C2	Shipping	Link			
Lithuania, Poland	CCS Baltic Consortium	Onshore pipeline/Shipping	Link			
Netherlands	Porthos	Onshore pipeline/Offshore pipeline	Link	Link	Link	Link
Netherlands	Aramis	Offshore pipeline	Link	Link		
Netherlands	L10	Shipping	Link	Link		
Netherlands, Belgium, Germany	Delta Rhyne Corridor	Onshore pipeline	Link	Link		
Netherlands	OCAP	Onshore pipeline	Link	Link		
Norway, Belgium, Finland, France, Germany, Netherlands, Sweden	Northern Lights	Shipping	Link	Link		
Poland	ECO2CEE	Onshore pipeline/Shipping	Link	Link		

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
joint-research-centre.ec.europa.eu

Publications Office of the European Union