Northern Lights

Carbon footprint of the Northern Lights JV CO_2 transport and storage value chain

Valentin Gentile[a], Gaelle Cauchois[a], Irina Ålund[a],,Nathalie Renzi[b],
[a]Carbon Limits,CJ Hambros plass 2A, 0164 Oslo, Norway
[b]Northern Lights JV, Byfjordparken 15, 4007 Stavanger, Norway

Abstract

In December 2020 the Norwegian government committed funding to the development of a full-scale carbon capture and storage (CCS) project named Longship. To materialize this project, 3 companies (Equinor, Shell and TotalEnergies) have established a joint venture, the Northern Lights JV, to oversee the transport and storage part of the chain.

The carbon footprint assessment of the Northern Lights value chain was performed to (1) take stock of the current situation and (2) identify further measures to reduce the carbon footprint of the value chain. Calculating the net GHG emissions per tonne of CO_2 stored is key to demonstrate that the Northern Lights CCS value chain is a viable concept effectively contributing to GHG emissions mitigation.

The assessment was performed following ISO 14040 / 14044 standards. As of March 2023, the Northern Lights infrastructure to transport and store CO_2 is still under construction and planning. As such, this study relies on currently available data and best estimates. Two development phases of the chain are envisaged (1.5 and 3.5MtCO_2 stored per year).

The results of assessment have shown that over the project lifetime (from construction to post closure of the storage site) for both phases of the development, a total of 3.32 MtCO_2e are expected to be emitted for a total of 127.8 MtCO_2 stored. In other words, 0.026 CO_2e are emitted per tonne of CO_2 stored. 91% of the emissions from the chain development and operation are coming from the transport part of the value chain, i.e. shipping.

Introduction

Carbon capture and storage (CCS) is the process of capturing CO_2 from natural or anthropogenic sources and storing it underground in deep saline formation or depleted oil and gas fields. As highlighted by the most recent Intergovernmental Panel on Climate Change (IPCC) report [1] carbon capture and storage (CCS) is an essential tool for reducing greenhouse gas emissions, as well as for achieving CO_2 removal from the atmosphere through direct air capture or bioenergy-based applications. CCS is one of the available mitigation options for reduction of CO_2 emissions along the gas value chain, the power and the industrial sectors. According to the IPCC technological deployment scenarios limiting global warming below 1.5 °C, CCS will have to cumulatively store a median average of 670 Gt of CO_2 by 2100 [1].

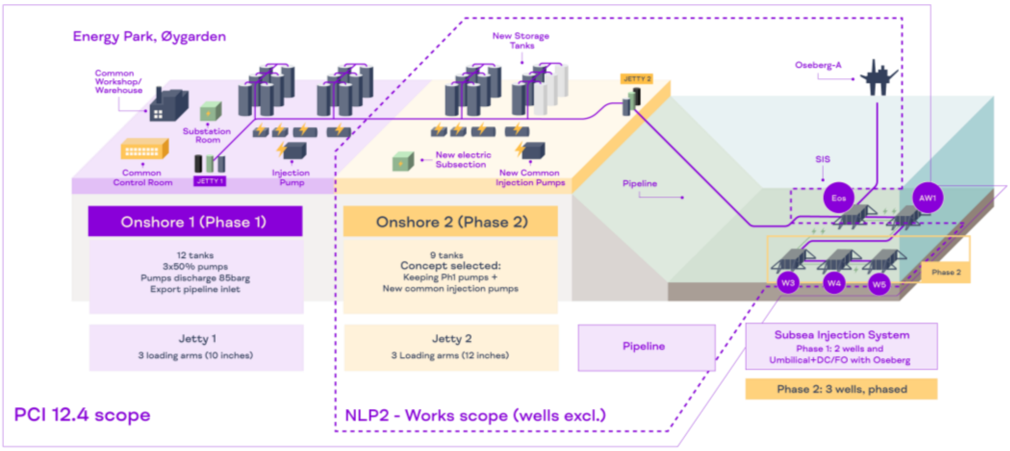
In December 2020 the Norwegian government committed funding to the development of a full-scale CCS project named Longship. By 2024, Longship aims at capturing CO_2 from industrial sources in the Oslo-fjord region (a cement and a waste to energy plant), transporting it to Øygarden onshore terminal, from where CO_2 is injected for permanent storage in a deep saline aquifer 2,600 meters under the seabed through a hundred kilometres long offshore pipeline and a subsea template [2]. To materialize this project, 3 companies (Equinor, Shell and TotalEnergies) have established a joint venture, the Northern Lights JV, to oversee the transport and storage part of the chain. Northern Lights JV plans to deliver CO_2 transport and storage services to other companies across Europe.

The company's main objective is to enable the decarbonisation of the European industry and to facilitate the removal of CO_2 from the atmosphere. The Northern Lights value chain has a role in enabling and opening the path for other similar projects. To store the IPCC projection of 670 Gt CO_2, more than 5200 Northern Lights JV projects would need to be deployed.

To assess the carbon footprint of their value chain, Northern Lights JV contracted Carbon Limits to adapt and update the carbon footprint tool developed for Gassnova in 2018 focusing on the transport and storage part of the Longship chain. The analysis was performed to take stock of the current situation and to identify further measures to reduce the value chain emissions. Indeed, activities pertaining to the Northern Lights value chain emit GreenHouse Gases (GHG) that could partly counterbalance the expected benefit of operating a CCS chain. Calculating the net GHG emissions per tonne of CO_2 stored is key to demonstrate that the Northern Lights CCS value chain is a viable concept effectively contributing to GHG emissions mitigation.

The Northern Lights value chain

Figure 1 Scope assessment of NL JV value chain for phase 1+2. Source: Northern lights JV



Legend:
SIS = Subsea Injection System / DC/FO = Direct Current Fiber Optic / Eos and AW1: P1 wells /Wx = P2 wells

As of March 2023, the Northern Lights' CO_2 transport and storage infrastructure for phase 1 is still under construction. Two development phases of the chain are envisaged: the first phase, comprising the Langskip volumes supported by the Norwegian government, will allow to store 1.5 MtCO2 per year, whereas the second phase will include an expansion for a total volume of approximately 3.5 Mt CO_2 per year. The injection activity is expected to last 25 years.

7,500 m3 ships are envisaged for the transport of the Phase 1 volumes, and a combination of 7,500 m3 and 12,000 m3 ships have been considered for the transport of the Phase 2 volumes in the assessment. Ships are running on Liquefied Natural Gas (LNG) with MDO (Marine Diesel Oil) as pilot fuel (secondary fuel). They are also equipped with rotor sail and air lubricating systems, which contribute to reducing fuel consumption by using wind propulsion when favourable and reducing the frictional resistance of the vessel.

In the assessment, the ships are assumed to transport CO_2 from Norway and Northern Europe.

Once the CO_2 reaches the onshore terminal in Øygarden, it is offloaded and stored in 12 storage tanks with a total capacity of 7,500 m3 before being pumped out to a 12-in diameter 100-km long offshore pipeline for well injection and storage between 2,000 and 3,000 m under the seabed. Additional tanks and pumping capacity will be necessary for Phase 2, while the offshore pipeline can already host the Phase 2 volumes.

An umbilical and DCFO cable are laid down on the seabed to bring all the necessary utilities, power, and signals to the subsea injection well.

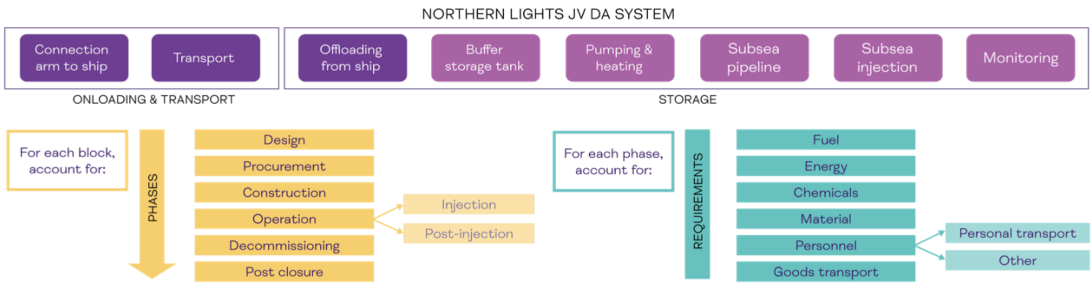
The injection well was drilled in 2021. A sidetrack of this well and a contingency well were drilled in 2022 as part of Phase 1. The assumption of three additional wells has been made for the Phase 2 expansion.

Methodology

The study was performed according to the ISO standards 14040 and 14044. The goal of the carbon footprint assessment is to account for all the emissions of greenhouse gases induced directly or indirectly during the entire lifecycle of Northern Lights activities. Figure 2 illustrates the scope of the analysis. Both transport and storage activities are included in the assessment. The chain starts with the loading activity at customer site, where the connecting arm to the ship is included in the assessment. The CO_2 is assumed to be already liquified by the customer. The system boundary stops with the monitoring of the geological reservoir.

For each activity, the design, procurement, construction, operation, decommissioning, post-injection and post closure phases are included. The post-injection phase is specific to the storage part of the chain: at the end of the injection, vessels will perform regular seismic campaigns - based on the outcomes of the previous campaigns - to ensure the CO_2 is behaving as modelled. After post-injection, the site is officially closed and transferred to the state. No physical activities are considered during this phase. As illustrated in Figure 2, for each life cycle stage, fuel, energy, chemicals, materials, personnel (both labour and personal transport), and transport of goods are accounted for when data were available.

Figure 2 - System boundaries



The functional unit of the system assessed is 1 tonne of CO_2 stored. This unit ensures that all direct and indirect emissions of the value chain are included in the assessment. The footprint is calculated based on activity data multiplied by corresponding emission factors. The activity data was provided by Northern Lights JV and their Technical Service Providers (Equinor-Stasco), in line with FEED reports for the facilities development in Øygarden, current developments in the project, information received from the shipyard in China and direct data from the construction activity.

Most of the emission factors were retrieved from the ecoinvent 3.8 Cutoff database. Table 1 shows the different sources of emission factors that were used in the analysis and the type of activity they were applied to. When the ecoinvent data was not relevant, other data sources were used to fit the activity. Most of these data sources come from peer-reviewed published tools, IPCC factors, peer-reviewed papers and expert judgement.

Table 1 Source of emission factors

Data Source	Type of activity
ecoinvent 3.8 Cutoff	Mobile and stationary fuels, electricity, thermal energy, chemicals, materials, transport, wastewater treatment, waste treatment and disposal
IFC Carbon Emission Estimation tool, 2014	Building and Road Construction
2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.2 Energy – Mobile Combustion / Stationary Combustion	Mobile and Stationary combustion
IPCC, 6th assessment report	Global warming potential – Emissions of GHGs
Experts	Fuel consumption offshore vessels
Others (e.g. peer reviewed papers)	Clearing – Preparation of the site, labour

Emission factors used in the assessment indicate a Global Warming Potential of the greenhouse gases over a 100-year time horizon (GWP100), which provides a common measurement unit for all GHG in kg of CO_2 equivalent. The emission factors retrieved from the ecoinvent database were estimated based on the CML impact methodology[1].

[1] [1]The CML methodology was selected for the current carbon footprint assessment as it is the most widely used methodology. This estimates the GWP at 100 years using indices from IPCC 2012 (4th Assessment Report). It was developed by the Institute of Environmental Sciences (Centrum voor Milieuwetenschappen) at the university of Leiden in the Netherlands. As all methodologies are relying on IPCC assessment reports, choosing one or the other would lead to the same assessment provided the GWP are from the same assessment report.

Conservative assumptions were made with regards to geographical coverage of emission factors. For processes without a certainty on their location, emission factors adjusted for a global coverage were applied. For processes with a defined location, emission factors with matching location coverage were selected when available. No impact allocation was necessary in this assessment as no process leads to the production of by-products. No criteria for data exclusion (cut-off) were applied in this assessment. When missing relevant data, consolidation efforts were made to estimate the main contributors in terms of mass and climate change significance.

The assessment characterized each activity and corresponding emission factors, with levels of confidence, as shown in the appendix. For activity data, the following confidence levels were used:

- High confidence: data from design documents
- Moderate confidence: data deduced from the design documents
- Low confidence: data estimated based on assumptions

For emission factors, the following were used:

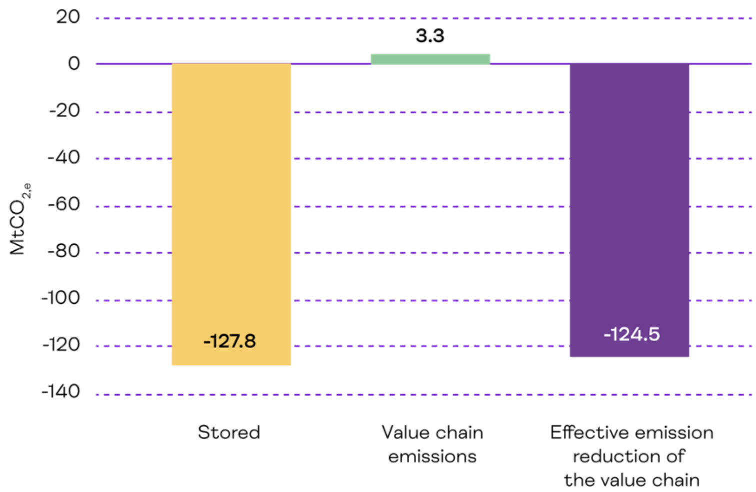
- High confidence: data found in verified databases, widely accepted data
- Moderate confidence: data from peer reviewed papers or expert judgement, high to moderate degree of consensus
- Low confidence: data from grey literature, moderate to low (or unknown) degree of consensus

Results

Over the project lifetime (from construction to post closure of the storage site for both injection phases), a total of 3.32 $MtCO_{2,e}$ are estimated to be emitted for a total of 127.8 $MtCO_2$ stored. In other words, 0.026 $tCO_{2,e}$ is estimated to be emitted per ton of CO_2 stored. This result shows that the whole value chain achieves an **effective emission reduction of 124.5$tCO_{2,e}$** as shown in (Figure 3) below

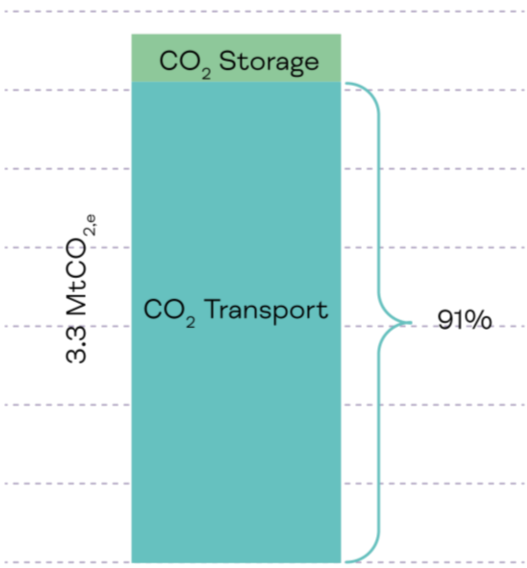
Figure 3 Total emissions and CO_2 stored

GHG emissions from implementation and operation of the Northern Lights value chain vs the amount of CO_2 stored.



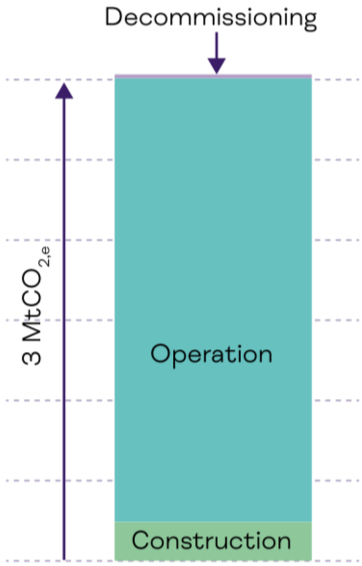
The transport part of the value chain (i.e. shipping) represents 91% of the total emissions as shown in (Figure 4).

Figure 4 GHG emissions from the Northern Lights' value chain



In the transport process, the operation phase is responsible for 91% of the transport emissions, while the construction phase and the decommissioning phase account for 8% and 1% of the total emissions from transport, respectively (Figure 5).

Figure 5 Lifecycle emissions from transport



As illustrated in (Figure 6) the main emission contributor from the operation phase is the ship fuel consumption (accounting for almost 87% of the transport emissions) including emissions from the supply chain and combustion of the fuel. Then, the other process emissions including methane slip from the LNG engine, purging of CO_2 tanks, and cooling down represent the remaining 4% of the total transport emissions during operation. The largest share of the emissions from the construction phase of the transport process, i.e. construction and delivery of ships for CO_2 transport, is attributed to the use of equipment and materials for construction (Figure 7), which accounts for 5% of the total emissions from the transport process

Figure 6 Operation emissions from ship transport

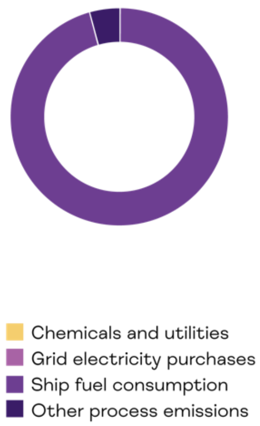
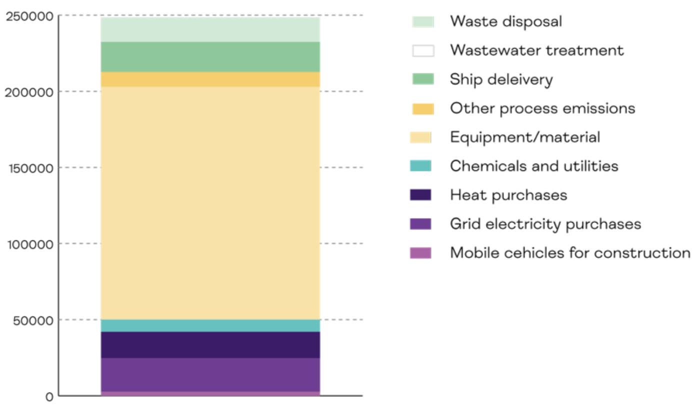
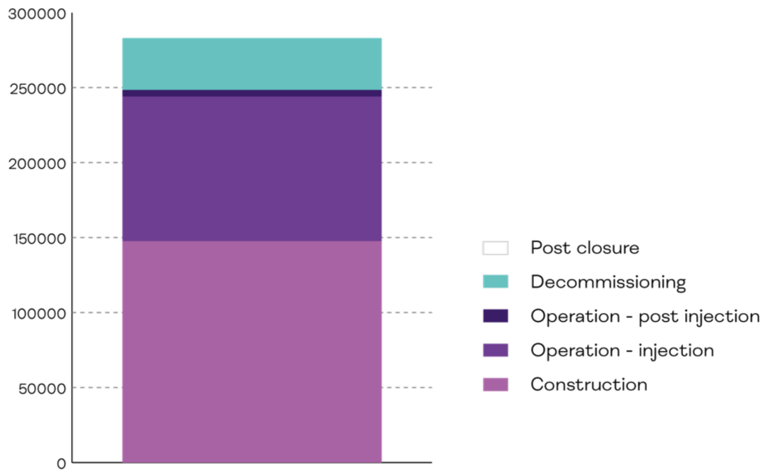


Figure 7 Construction emissions from ship transport



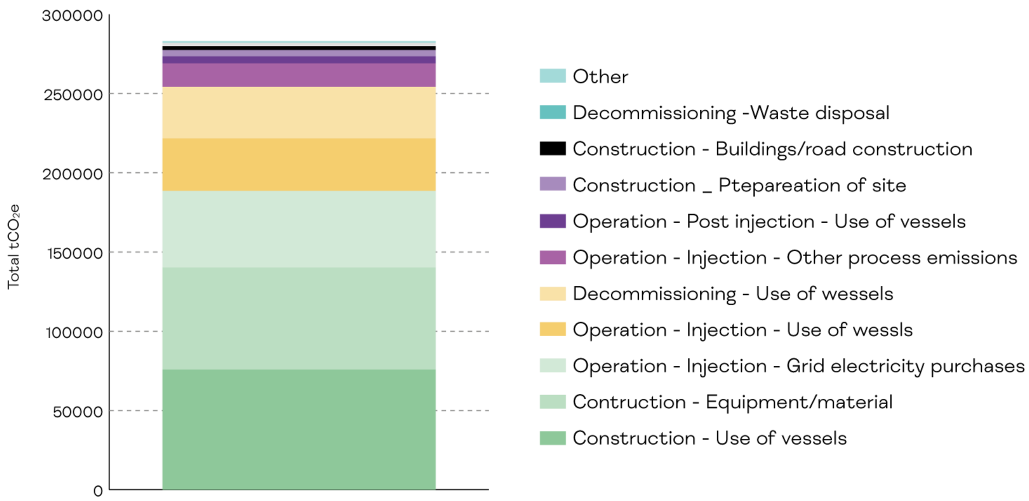
With regards to storage (9% of the total emissions), the construction phase is responsible for 52% of the storage emissions while the operational phase represents 34% of the storage emissions (Figure 8).

Figure 8 Lifecycle emissions for storage



Among the top 10 contributors to the emissions from the storage part of the value chain (Figure 9), the use of vessels for the offshore operations during the value chain lifecycle represents 51% of the storage emissions. Equipment for construction (e.g. steel for pipeline, storage tanks, subsea template and well) and electricity purchases account for 23% and 17% of the storage emissions respectively. In the overall carbon footprint, these processes represent 1.9% (equipment for construction) and 1.5% (electricity purchases) of the total emissions over the value chain lifecycle.

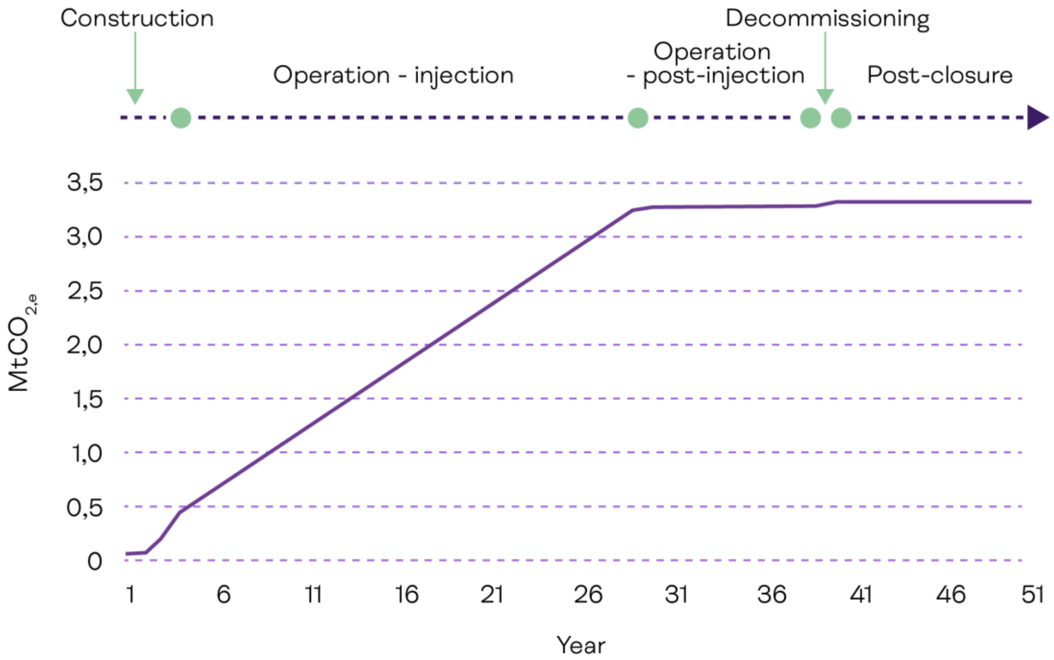
Figure 9 Top 10 emission contributors from storage



Emissions over lifetime

The graph below (Figure 10) shows the evolution of the cumulated GHG emissions during all lifetime phases assessed over the project lifetime. The GHG emissions start with construction and increase steadily over the operation phase, mostly driven by the fuel consumption for the shipping operation. Then, decommissioning activities lead to a slight increase towards the end of the value chain lifecycle.

Figure 10 Total cumulated GHG emissions of the value chain over the full lifecycle



The total cumulative emissions over the lifetime of the whole value chain (3.32Mt - See (Figure 10) are balanced out by the amount of CO_2 stored after the two first years of operation. This demonstrates that the Northern Lights value chain is effectively contributing to GHG emissions mitigation.

On uncertainty of activity data

The project is still under development. This implies that some of the activity data used in the assessment had to be estimated based on conservative assumptions. When available, the exact amounts as reported by service providers were used in the calculations. For activities with missing data, estimation and data gathering were focused on the main items/categories. For example, the data gathering process ensured that an estimation of steel required was registered in the materials for ship construction. For the decommissioning activity, it was assumed that materials and equipment used for construction would be sent to waste treatment.

As the logistics and routing are still under optimization, a conservative value for fuel consumption by ships was used in the study with the information available at that time. Conservative assumptions were also made for the activities related to use of vessels for offshore operations, since some of them will depend on the results of previous seismic campaigns.

Discussion

The overall carbon footprint of the Northern Lights value chain is relatively low with 0.026 $tCO_{2,e}$ emitted per ton of CO_2 stored. Several factors can explain this number including but not limited to the already built-in low carbon options like the use of LNG as a maritime transport fuel and the use of optimized engine type. In addition, the location of the project ensures a low carbon grid emission factor.

Fugitive emissions estimated along the value chain are linked to purges of tanks, fugitive emissions and maintenance operations (not including unplanned events) and are evaluated at 96,725 tCO_2 for 127.8 $MtCO_2$ stored overall, i.e. 0.076% of the volume of stored CO_2.

The chain is developed with best available technologies. Though the carbon footprint is low in comparison to the amount of CO_2 stored, Northern Lights JV is studying possibilities to further reduce the emissions from the chain. As emissions from fuel consumption on ship account for 65% of the overall carbon footprint of the Northern Lights' activities (2.15 $MtCO_{2,e}$ compared to 3.32 $MtCO_{2,e}$ for the whole value chain), several mitigation options are being studied to reduce the impact of this emission source. Among such mitigation options are:

- Partial or full fuel switch to LBG, depending on the available LBG supply and on the logistics or/and
- Onboard carbon capture of the emissions from the ships operating during Phase 2.

The applicability and the potential impact of these options on the emissions from the overall value chain are still under evaluation. Other low carbon products and services (steel, cement or low carbon vessels for storage operations) have not been considered to be implementable just yet.

In addition, Northern Lights JV is assessing how the estimated emissions remaining after the implementation of mitigation measures could be compensated.

Conclusion

The main objective of Northern Lights JV is to enable the decarbonization of the European industry by providing a service of CO_2 transport and storage. Following an LCA approach, the carbon footprint assessment that the implementation and operation of the Northern Lights chain leads to GHG emissions of 0.026 $tCO_{2,e}$ per tonne of CO_2 stored including both Phases 1 and 2. Considering the amount of CO_2 stored with respect to the emissions generated from the implementation of the Northern Lights value chain over its full lifecycle, the transport, injection and storage services provided by Northern Lights JV ensure an effective emission abatement corresponding to approximately 97.4% of the amount of CO_2 sent for storage.

Northern Lights

This result highlights the viability of the Northern Lights JV value chain in effectively storing more CO_2 than what it emits. To further improve the carbon footprint of the value chain, Northern Lights JV is currently studying additional mitigation options and compensation mechanisms.

References

[1] IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

[2] https://norlights.com/about-the-longship-project/

Appendix 1 - Results for transport activities

	Process	Total tCO_2e	Phase 1 + Phase 2 Confidence level input data	Phase 1 Confidence level EF
CONSTRUCTION	Mobile vehicles for construction	2 682		
	Grid electricity purchases	22 054		
	Heat purchases	17 259		
	Equipment/material	152 946		
	Other process emissions	9 720		
	Ship delivery	19 781		
	Wastewater treatment	0.12		
	Waste disposal	16 088		
OPERATION	Chemicals and utilities	3 409		
	Grid electricity purchases	5 492		
	Heat purchases			
	Equipment/material			
	Ship fuel consumption	2 638 032		
	Other process emissions	124 638		
	Waste disposal			
DECOMMIS-SIONING	Fuel consumed in mobile vehicles			
	Grid electricity purchases			
	Heat purchases			
	Wastewater treatment			
	Waste disposal	16 129		

Appendix 2 - Results for storage activities

	Process	Total tCO_2e	Phase 1 + Phase 2 Confidence level input data	Phase 1 Confidence level EF
CONSTRUCTION	Preparation of the site	4 028		
	Buildings/road construction	2 416		
	Mobile vehicles for construction			
	Equipment/material	64 469		
	Chemicals and utilities	978		
	Other process emissions			
	Grid electricity purchases			
	Heat purchases			
	Stationary combustion			
	Use of vessels	75 741		
	Wastewater treatment			
	Solid wate disposal			
OPERATION	INJECTION - Stationary combustion			
	INJECTION - Chemicals and utilities	119		
	INJECTION - Grid electricity purchases	48 329		
	INJECTION - Heat purchases			
	INJECTION - Fuel consumed in mobile vehicles			
	INJECTION - Other process emissions	14 848		
	INJECTION - Equipment/material			
	INJECTION - Wastewater treatment			
	INJECTION - Solid wate disposal			
	INJECTION - Use of vessels	33 065		
	INJECTION - Labour			
	INJECTION - Personal transport			
	POST INJECTION - Grid electricity purchases			
	POST INJECTION - Other process emissions			
	POST INJECTION - Use of vessels	4 406		
DECOMMISSIONING	Clearing onshore			
	Fuel consumed in mobile vehicles			
	Wastewater treatment			
	Waste disposal	2 162		
	Equipment/material			
	Use of vessels	32 507		
	Grid electricity purchases			
	Heat purchases			
POST CLOSURE	Use of vessels			

Level of confidence – activity data

	High confidence: data from design documents
	Moderate confidence: data deducted from the design documents
	Low confidence: data estimated from assumptions

Level of confidence – emission factors

	High confidence: data found in verified databases, widely accepted data
	Moderate confidence: data from peer reviewed papers or expert jugdement, high to moderate degree of consenus
	Low confidence: data from grey literature, moderate to low (or unknown) degree of consensus