HI WEST 41 (Advanced)
DK Hydrogen Storage

ENERGINET

Reasons for grouping [ENTSOG]

The project group is a stand-alone underground storage in Denmark. This project will enable storage of hydrogen in Denmark by 2026 (HYD-A-1238).

Objective of the group [Promoter]

Create hydrogen storage that deliver on following values:

Arbitrage value
Storage enables a liquid market for hydrogen. Giving trading companies the option to buy/sell at competitive prices. This will at the end of the day benefit the consumer of hydrogen.

System value
Storage enables balancing of the entire energy system across power and hydrogen. Increasing load factor of entire energy system (more running hours of RE and PtX plants as well as high load factor on power grid and H2 pipelines). Hence reduces the need for infrastructure build out.

Security value
Storage provides security of supply across the entire energy system.

Kick Start value
Deliver risk reduction for customers starting a new value chain

Environmental value
Enable more running hours of the entire Renewable Energy system across the whole value chain. Hence decreasing the CO2 emission by replacing fossil fuel consumption.

A. Project group technical information [Promoter/ ENTSOG]

Project technical information [Promoter]

Storage

TYNDP Project code	Maximum Injection rate [GWh/d]	Maximum Withdrawal rate [GWh/d]	Working gas volume [GWh]
HYD-A-1238	3,16	9,5	116

Capacity increment [ENTSOG]

TYNDP Project code	Point name	Operator	From system	To system	Capacity increment [GWh/d]	Comm. year
HYD-A-1238	H2_ST_DK	Energinet	Transmission Denmark (DK Hydrogen)	Storage Denmark (DK Hydrogen)	3,16	2026
HYD-A-1238	H2_ST_DK	Energinet	Storage Denmark (DK Hydrogen)	Transmission Denmark (DK Hydrogen)	9,5	2026

B. Project Cost Information

During the TYNDP 2022 Project Data Collection, promoters were asked to indicate whether their costs were confidential or not. The following tables display the non-confidential costs provided by the promoters (as of December 2022, end of PCI project collection). The amounts provided can differ from the figures used by the project promoters in other contexts, where costs can be updated and/or evaluated using different methodologies or assumptions.

[ENTSOG]

TYNDP Project code	CAPEX [M€]	CAPEX range [%]	OPEX [M€]	OPEX range [%]
HYD-A-1238	100	20	3	20

Description of the cost and range [Promoter]

The capacities and related costs are all based on converting 1 methane cavern to hydrogen and construction of a hydrogen topside.
Gas Storage Denmark expect to convert multiple of its methane caverns to hydrogen in the period up until 2040.

C. Project Benefits [ENTSOG]

C.1 Summary of benefits

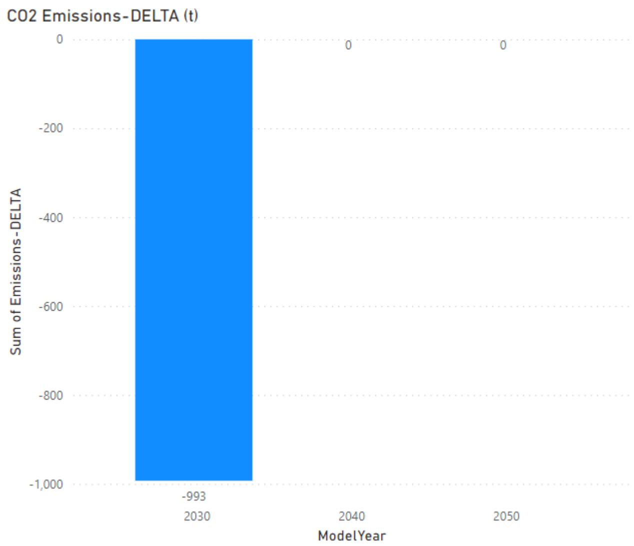
This section provides a summarised analysis by ENTSOG of the main benefits stemming from the realisation of the overall group. More details on the indicators are available in Annex D of TYNDP 2022[1].

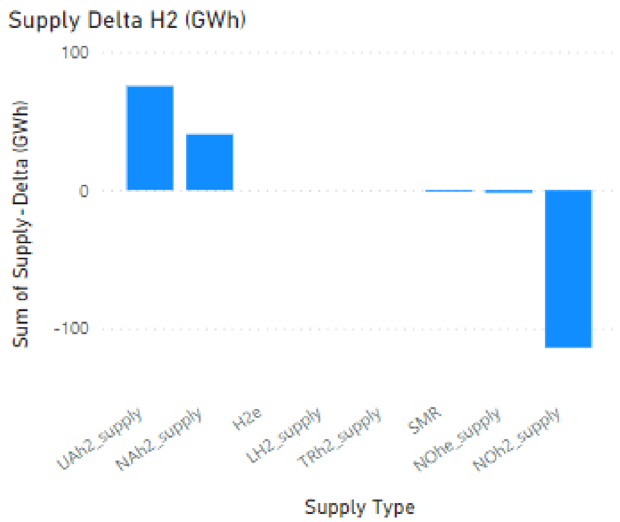
Distributed Energy

In 2026, the new storage in Denmark allows hydrogen to be stored for climatic stresses or international disruption.

Sustainability

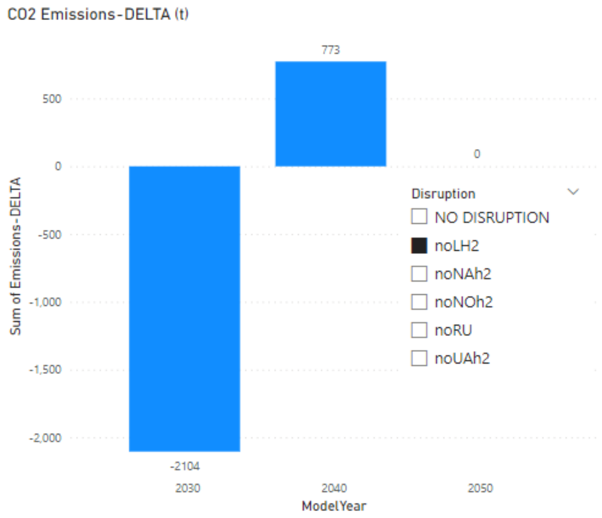
In reference case, the storage will contribute to sustainability by reducing overall CO_2 emissions by 993 t in 2030. This is explained as the project group, will increase flexibility of hydrogen supplies, allowing for the replacement of blue hydrogen supplies from Norway , with green hydrogen supplies.

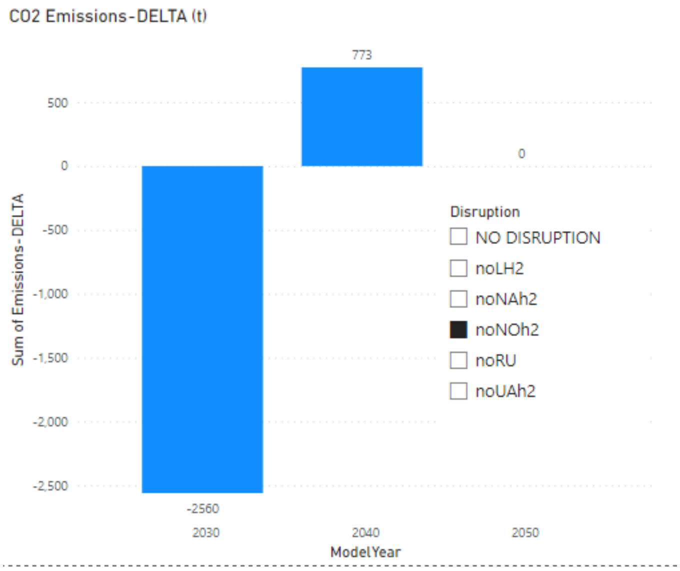


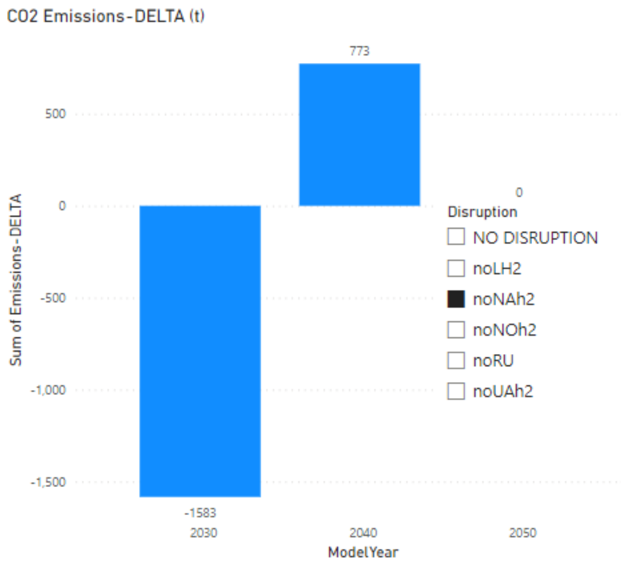


Furthermore, almost same sustainability benefits are expected under other supply disruption cases in 2030. However, in 2040 triggered by the higher hydrogen demand, the project group will increase overall CO_2 emissions. Due to the higher cooperation between countries more hydrogen demand curtailment can be avoided by storing hydrogen produced from SMR.

[1] https://www.entsog.eu/sites/default/files/202304/ENTSOG_TYNDP_2022_Annex_D_Methodology_230411.pdf







Security of Supply:[2]

> Reference case

[2] *As for the hydrogen system there is no existing infrastructure level available yet, ENTSOG has identified a possible hydrogen network according to the information provided by promoters in their project submission for the TYNDP/PCI process (i.e., H2 Infrastructure level). Therefore, the System Assessment shows the results that could be reached (for different timestamps) under the hypothesis of a full commissioning of the H2 infrastructure projects that were submitted by project promoters but that are not yet in place. Therefore, even in configurations where no demand curtailment is identified (e.g., average winter in 2030) these results should not be read as an absence of H2 infrastructure needs for the given scenario. On the contrary, the full availability of the planned infrastructures composing the H2 infrastructure level is assumed to avoid the potential demand curtailment.*

2030 DE- Benefits

2040 DE- Benefits

2050 DE- Benefits

In the reference case, the project is not contributing to further mitigation of hydrogen demand curtailment risk in average summer and average winter.

> Climatic stress cases

Under 2 -week and 2-week dunkelflaute climatic stress case, as well as under peak day climatic case the project group is also not showing security of supply benefits.

> Disruption cases (S-1):

Similarly, under supply disruption cases, the project group is not further contributing to the mitigation of hydrogen demand curtailment rest.

> Single largest capacity disruption (SLCD):

SLCD Benefits - 2030 - Distributed Energy

SLCD Benefits - 2040 - Distributed Energy

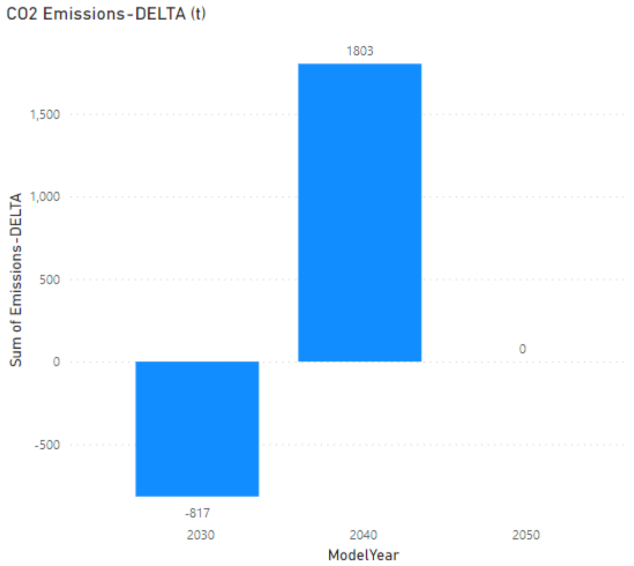
SLCD Benefits - 2050 - Distributed Energy

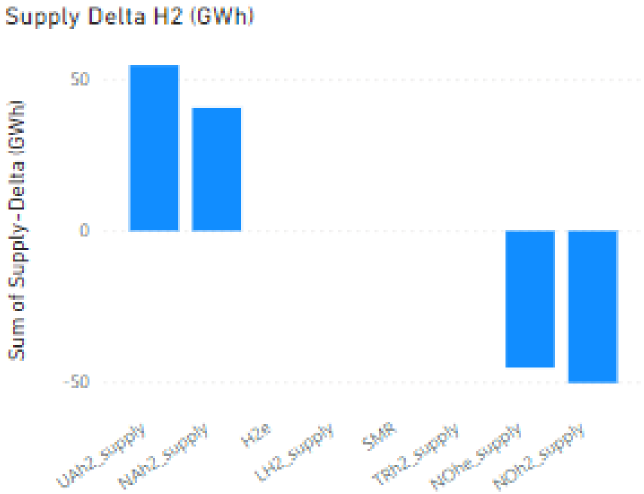
In case of single largest capacity disruption (SLCD), the storage reduces a little (1-2%) the risk of demand curtailment in all European countries from 2040.

Global Ambition

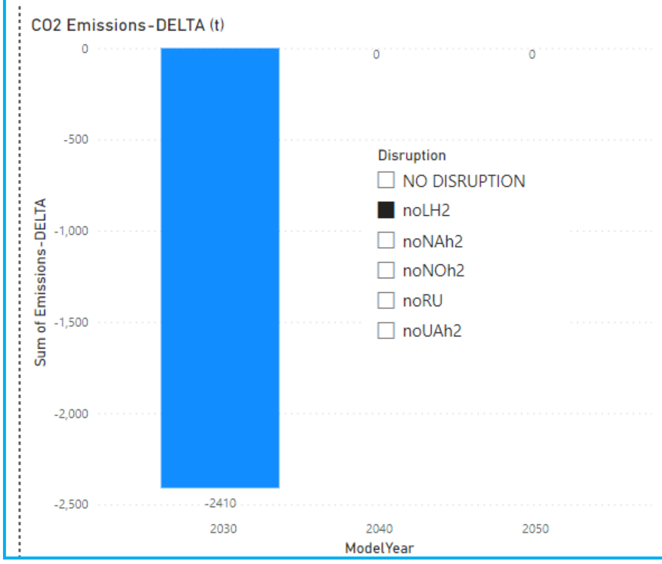
Sustainability

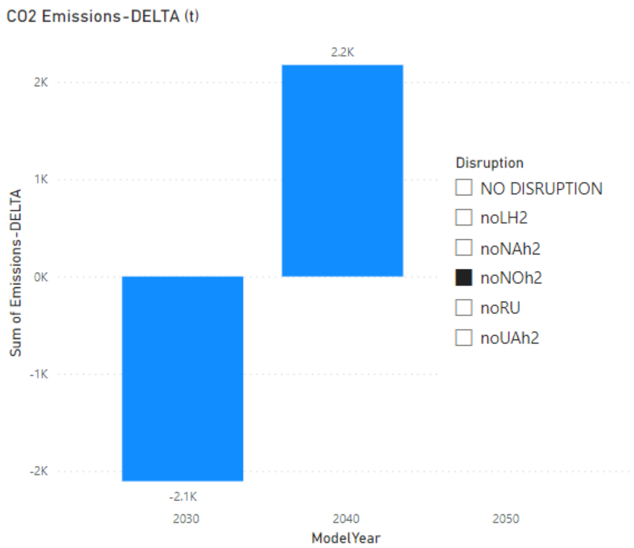
In reference case, the storage will contribute to sustainability by reducing overall CO_2 emissions by 817 t in 2030. This is explained as the project group, will increase flexibility of hydrogen supplies, allowing for the replacement of blue hydrogen supplies from Norway , with green hydrogen supplies. However, in 2040 triggered by the higher hydrogen demand, the project group will increase overall CO_2 emissions. Due to the higher cooperation between countries more hydrogen demand curtailment can be avoided by storing hydrogen produced from SMR.

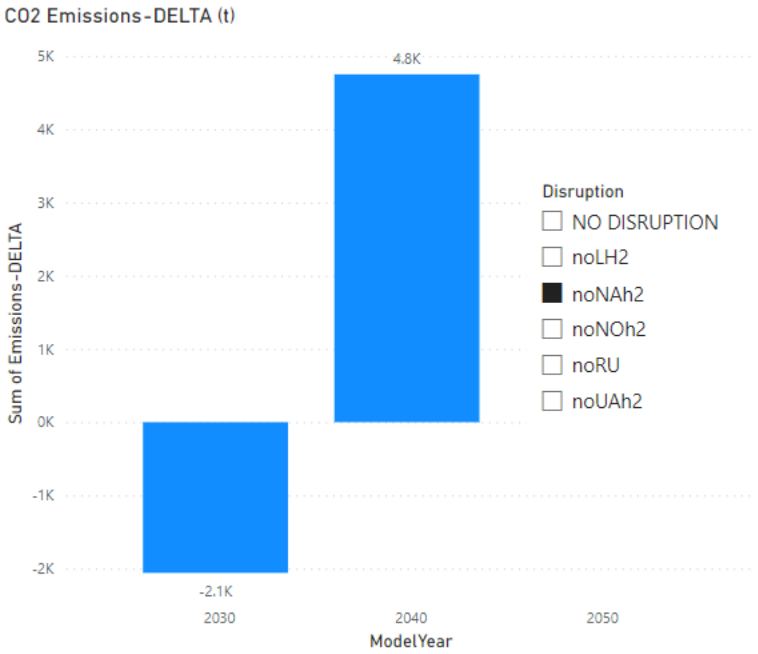




Similar trend for sustainability benefits is observed under different supply disruption cases.

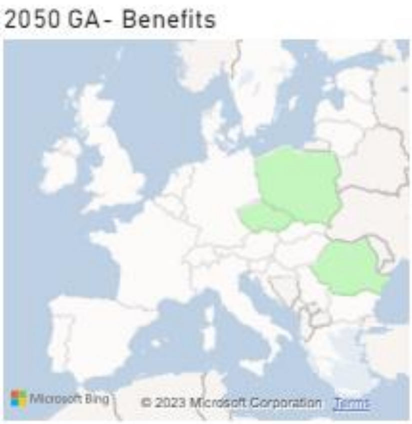






Security of supply benefits

> Reference case



In the reference case, the storage is not contributing to further mitigation of hydrogen demand curtailment risk in average summer and average winter in 2030 and 2040. In 2050, the storage can mitigate demand curtailment in some eastern countries, up to 2%.

> Climatic stress cases

Under 2 -week and 2-week dunkelflaute climatic stress case, as well as under peak day climatic case the project group is also not showing security of supply benefits.

> Disruption cases (S-1)

Similar to reference case and climatic stress cases the project is not further mitigating the demand curtailment risk in case of disruption cases.

> Single largest capacity disruption (SLCD)

Benefits 100% - 20% 20% - 5% 5% - 0%

In case of single largest capacity disruption (SLCD), the storage reduces a little (1-2%) the risk of demand curtailment in all European countries in 2040.

SLCD Benefits - 2030 - Global Ambition

SLCD Benefits - 2040 - Global Ambition

SLCD Benefits - 2050 - Global Ambition

C.2 Quantitative benefits [ENTSOG]

The following tables display all the benefits quantified by ENTSOG through specific indicators and stemming from the realisation of the considered project group.

CO2 Emissions:

ModelYear	Disruption	Scenario	Unit	Emissions-DELTA	Emissions-PLUS	Emissions-MINUS
2030	NO DISRUPTION	DE	tonne	-992,88	538677299	538678291,9
2030	noLH2	DE	tonne	-2103,95	540175890,2	540177994,2
2030	noNAh2	DE	tonne	-1582,71	539785356,1	539786938,8
2030	noNOh2	DE	tonne	-2559,58	538877197,8	538879757,4
2030	noUAh2	DE	tonne	0,00	539378771,9	539378771,9
2030	NO DISRUPTION	GA	tonne	-816,64	592910448,4	592911265,1
2030	noLH2	GA	tonne	-2409,93	594817481,2	594819891,1
2030	noNAh2	GA	tonne	-2057,53	594141433,2	594143490,7
2030	noNOh2	GA	tonne	-2104,88	593310994,3	593313099,1
2030	noUAh2	GA	tonne	0,00	593627617,9	593627617,9
2040	NO DISRUPTION	DE	tonne	0,00	392077044	392077044
2040	noLH2	DE	tonne	772,68	392213883,4	392213110,7
2040	noNAh2	DE	tonne	772,68	392188097,7	392187325
2040	noNOh2	DE	tonne	772,68	392144022,6	392143249,9
2040	noUAh2	DE	tonne	772,68	392399182,9	392398410,2
2040	NO DISRUPTION	GA	tonne	1802,92	396523251,6	396521448,7
2040	noLH2	GA	tonne	0,00	397455196,7	397455196,7
2040	noNAh2	GA	tonne	4750,64	397301976,6	397297226
2040	noNOh2	GA	tonne	2175,04	397450977,1	397448802,1
2040	noUAh2	GA	tonne	0,00	397478498,3	397478498,3
2050	NO DISRUPTION	DE	tonne	0,00	232557734,8	232557734,8
2050	noLH2	DE	tonne	0,00	232557734,8	232557734,8
2050	noNAh2	DE	tonne	0,00	232557734,8	232557734,8
2050	noNOh2	DE	tonne	0,00	232557734,8	232557734,8
2050	noRU	DE	tonne	0,00	232557734,8	232557734,8
2050	noUAh2	DE	tonne	0,00	232557734,8	232557734,8
2050	NO DISRUPTION	GA	tonne	0,00	228306706,5	228306706,5
2050	noLH2	GA	tonne	0,00	228306706,5	228306706,5
2050	noNAh2	GA	tonne	0,00	228306706,5	228306706,5
2050	noNOh2	GA	tonne	0,00	228306706,5	228306706,5
2050	noRU	GA	tonne	0,00	228306706,5	228306706,5
2050	noUAh2	GA	tonne	0,00	228306706,5	228306706,5

Curtailment Rate (SLCD):

Country	2030-DE-DELTA	2030-GA-DELTA	2040-DE-DELTA	2040-GA-DELTA	2050-DE-DELTA	2050-GA-DELTA
Austria	-1%	-1%	-2%	-1%	-2%	0%
Belgium	-1%	-1%	-2%	-1%	-1%	0%
Czechia	-1%	-1%	-2%	-2%	-2%	-1%
Denmark	-31%	-26%	-2%	-1%	-1%	0%
Estonia	-1%	-1%	-2%	-1%	-2%	-1%
Finland	-1%	-1%	-2%	-1%	-2%	-1%
Germany	-1%	-1%	-2%	-2%	-1%	0%
Latvia	-1%	-1%	-2%	-1%	-1%	-1%
Lithuania	-1%	-1%	-2%	-1%	-1%	-1%
Poland	-1%	-1%	-2%	-1%	-1%	0%
Portugal	-1%	-1%	-2%	-1%	0%	-1%
Slovenia	0%	0%	-2%	-1%	-1%	0%
Sweden	-1%	-1%	-2%	-1%	-2%	-1%
Switzerland	0%	0%	-2%	-1%	-1%	-1%
The Netherlands	0%	0%	-2%	-1%	-2%	0%
France	-1%	-1%	-2%	-1%	-1%	-1%
Italy	-1%	-1%	-1%	-1%	-2%	0%
Bulgaria	-1%	-1%	-1%	0%	0%	0%
Croatia	0%	0%	-1%	-1%	0%	-1%
Greece	-1%	0%	-1%	0%	0%	0%
Hungary	-1%	-1%	-1%	-1%	0%	-1%
Romania	0%	-1%	-1%	0%	0%	0%
Slovakia	-1%	-1%	-1%	-1%	0%	-1%
Spain	-1%	-1%	-1%	-1%	-2%	0%

Curtailment Rate (Climatic Stress):

SimulationPeriod	Country	2030-DE-DELTA	2030-GA-DELTA	2040-DE-DELTA	2040-GA-DELTA	2050-DE-DELTA	2050-GA-DELTA
Average2W	Austria	-1%	0%	0%	0%	0%	0%
Average2W	Belgium	0%	0%	0%	0%	0%	0%
Average2W	Bulgaria	0%	0%	0%	-1%	0%	0%
Average2W	Croatia	0%	0%	0%	0%	0%	0%
Average2W	Cyprus	0%	0%	0%	0%	0%	0%
Average2W	Czechia	-1%	0%	0%	0%	0%	0%
Average2W	Denmark	0%	0%	0%	-1%	0%	0%
Average2W	Estonia	0%	0%	0%	0%	0%	0%
Average2W	Finland	0%	0%	0%	0%	0%	0%
Average2W	France	0%	0%	0%	0%	0%	0%
Average2W	Germany	0%	0%	0%	0%	0%	0%
Average2W	Greece	0%	0%	0%	0%	0%	0%
Average2W	Hungary	0%	-1%	0%	0%	0%	0%
Average2W	Ireland	0%	0%	0%	0%	0%	0%
Average2W	Italy	0%	0%	0%	0%	0%	0%
Average2W	Latvia	0%	0%	0%	0%	0%	0%

Average2W	Lithuania	0%	0%	0%	0%	0%	0%
Average2W	Luxembourg	0%	0%	0%	0%	0%	0%
Average2W	Malta	0%	0%	0%	0%	0%	0%
Average2W	Poland	0%	0%	0%	0%	0%	0%
Average2W	Portugal	0%	0%	0%	0%	0%	0%
Average2W	Romania	0%	0%	0%	0%	0%	0%
Average2W	Serbia	0%	0%	0%	0%	0%	0%
Average2W	Slovakia	0%	0%	0%	0%	0%	0%
Average2W	Slovenia	0%	0%	0%	-1%	0%	0%
Average2W	Spain	0%	0%	0%	0%	0%	0%
Average2W	Sweden	0%	-1%	0%	0%	0%	0%
Average2W	Switzerland	0%	0%	0%	0%	0%	0%
Average2W	The Netherlands	0%	0%	0%	-1%	0%	0%
Average2W	United Kingdom	0%	0%	0%	0%	0%	0%
Average2WDF	Austria	0%	0%	0%	0%	0%	0%
Average2WDF	Belgium	0%	0%	0%	0%	0%	0%
Average2WDF	Bulgaria	0%	0%	0%	0%	0%	0%
Average2WDF	Croatia	0%	0%	0%	0%	0%	0%
Average2WDF	Cyprus	0%	0%	0%	0%	0%	0%
Average2WDF	Czechia	0%	0%	0%	0%	0%	0%
Average2WDF	Denmark	0%	0%	0%	0%	0%	-1%
Average2WDF	Estonia	0%	0%	0%	0%	0%	0%
Average2WDF	Finland	0%	0%	0%	-1%	0%	0%
Average2WDF	France	0%	0%	0%	0%	0%	0%
Average2WDF	Germany	0%	0%	0%	0%	0%	0%
Average2WDF	Greece	0%	0%	0%	0%	0%	0%
Average2WDF	Hungary	0%	-1%	0%	0%	0%	0%
Average2WDF	Ireland	0%	0%	0%	0%	0%	0%
Average2WDF	Italy	0%	0%	0%	0%	0%	0%
Average2WDF	Latvia	0%	0%	0%	0%	0%	0%
Average2WDF	Lithuania	0%	0%	0%	0%	0%	0%
Average2WDF	Luxembourg	0%	0%	0%	0%	0%	0%
Average2WDF	Malta	0%	0%	0%	0%	0%	0%
Average2WDF	Poland	0%	0%	0%	0%	0%	0%
Average2WDF	Portugal	0%	0%	0%	0%	0%	0%
Average2WDF	Romania	0%	0%	0%	0%	0%	0%
Average2WDF	Serbia	0%	0%	0%	0%	0%	0%
Average2WDF	Slovakia	0%	0%	0%	0%	0%	0%
Average2WDF	Slovenia	0%	0%	0%	0%	0%	0%
Average2WDF	Spain	0%	0%	0%	-1%	0%	0%
Average2WDF	Sweden	0%	-1%	0%	0%	0%	0%
Average2WDF	Switzerland	0%	0%	0%	0%	0%	-1%
Average2WDF	The Netherlands	0%	0%	0%	0%	0%	0%
Average2WDF	United Kingdom	0%	0%	0%	0%	0%	0%
DC	Austria	0%	-1%	0%	0%	0%	0%

DC	Belgium	0%	0%	0%	0%	0%	0%
DC	Bulgaria	0%	0%	-1%	0%	0%	0%
DC	Croatia	0%	0%	-1%	0%	0%	0%
DC	Cyprus	0%	0%	0%	0%	0%	0%
DC	Czechia	0%	0%	0%	0%	0%	0%
DC	Denmark	-1%	0%	0%	0%	0%	0%
DC	Estonia	0%	0%	0%	0%	0%	0%
DC	Finland	0%	0%	0%	0%	0%	0%
DC	France	0%	0%	-1%	0%	0%	0%
DC	Germany	-1%	0%	0%	0%	0%	0%
DC	Greece	0%	0%	-1%	0%	0%	0%
DC	Hungary	0%	0%	0%	0%	0%	0%
DC	Ireland	0%	0%	0%	0%	0%	0%
DC	Italy	0%	-1%	0%	0%	0%	0%
DC	Latvia	0%	0%	0%	0%	0%	0%
DC	Lithuania	0%	0%	0%	0%	0%	0%
DC	Luxembourg	0%	0%	0%	0%	0%	0%
DC	Malta	0%	0%	0%	0%	0%	0%
DC	Poland	0%	0%	0%	0%	0%	0%
DC	Portugal	0%	0%	-1%	0%	0%	0%
DC	Romania	0%	0%	0%	0%	0%	0%
DC	Serbia	0%	0%	0%	0%	0%	0%
DC	Slovakia	0%	-1%	-1%	0%	0%	0%
DC	Slovenia	0%	0%	-1%	0%	0%	0%
DC	Spain	0%	-1%	0%	0%	0%	0%
DC	Sweden	0%	0%	0%	0%	0%	0%
DC	Switzerland	0%	0%	0%	0%	-1%	0%
DC	The Netherlands	0%	0%	0%	0%	0%	0%
DC	United Kingdom	0%	0%	0%	0%	0%	0%

D. Environmental Impact [Promoter]

Any gas infrastructure has an impact on its surroundings. This impact is of particular relevance when crossing some environmentally sensitive areas. Mitigation measures are taken by the promoters to reduce this impact and comply with the EU and National regulations.

TYNDP Code	Type of infrastructure	Surface of impact	Environmentally sensitive area
HYD-A-1238	Under ground storage	Farm land	None

Potential impact	Mitigation measures	Related costs included in project CAPEX and OPEX	Additional expected costs
Very limited visual impact	Trees/hedges will be planted to shield visual impact	Already included as part of CAPEX 100,000 euro	

Environmental Impact explained [Promoter]

The impact will be very limited since most of the work will be done under ground on our existing storage site. The new build on green field will be limited in size and height and only have visual impact in a very thinly populated area. The green field topside will be shielded by hedges or trees.

E. Other benefits [Promoter]

Missing benefits are all benefits of a project which may be not captured by ENTSOG analysis.

As a necessary condition a missing benefit cannot have discrepancies with the benefits already covered by the assessment run by ENTSOG and this condition needs to be proved and justified.

Description of Other benefits [Promoter]

The ENTSOG analysis unfortunately doesn't capture the essential values this project strives to deliver. Values as described below:

Arbitrage value

Storage enable a liquid market for hydrogen. Giving trading companies the option to buy/sell at competitive prices. This will at the end of the day benefit the consumer of hydrogen.

System value

Storage enables balancing of the entire energy system across power and hydrogen. Increasing load factor of entire energy system(more running hours of RE and PtX plants as well as high load factor on power grid and H2 pipelines). Hence reduces the need for infrastructure build out

Security value

Storage provide security of supply across the entire energy system

Kick Start value

Deliver risk reduction for customers starting a new value chain

Environmental value

Enable more running hours of the entire Renewable Energy system across the whole value chain. Hence decreasing the CO2 emission by replacing fossil fuel consumption.

Below a simplified calculation of sustainability benefits for a cavern:

Let's assume that 1 kWh stored green hydrogen replaces 1 kWh Methane. Burning 1 kWh Methane leads to a CO2 emission of 205 gr. Our simulations show us that we will have up to 10 cycles a year pr. cavern. The simple example shown above is the result for 1 cavern.

	Throughput Working gas volume **single** cycle kWh
Hydrogen in 1 cavern kWh	120.000.000
Hydrogen in 1 cavern kg	3.500.000
Saved CO2 in tons/year comparing with Methane	24.600

Let's assume that 1 kg stored green hydrogen replaces 1 kg blue hydrogen. Producing 1 kg blue hydrogen leads to a CO2 emission of the median of 1,5 kg and 5 kg=3,25 kg. Our simulations show us that we will have up to 10 cycles a year pr. cavern. The simple example shown above is the result for 1 cavern.

	Throughput Working gas volume **single** cycle kWh
Hydrogen in 1 cavern kWh	120.000.000
Hydrogen in 1 cavern kg	3.500.000
Saved CO2 in tons/year comparing with blue hydrogen	11.375

F. Useful links [Promoter]

Useful links: