Re-Stream

Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe

Key figures

DNV

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This report was prepared by Carbon Limits AS and DNV AS for:

The project team thanks the Associations and their members for their trust, their participation in and their feedbacks on the Re-stream study.

Project title:
Re-Stream - Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe

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Carbon Limits works with public authorities, private companies, finance institutions and non-governmental organizations to reduce emissions of greenhouse gases from a range of sectors. Our team supports clients in the identification, development and financing of projects that mitigate climate change and generate economic value, in addition to providing advice in the design and implementation of climate and energy policies and regulations.

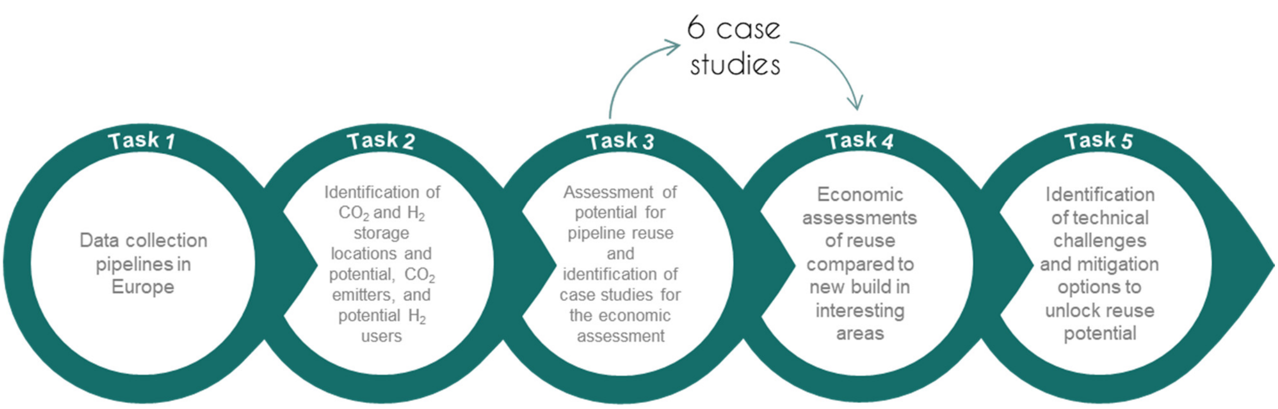
The main objectives of the Re-stream study are:

- To assess the potential for reuse of infrastructure in Europe (EU 27, UK and Norway) for CO_2 and hydrogen transport by mapping infrastructure and assessing its potential availability (before reuse), compatibility and capacity (if reused);
- Identify CO_2 and hydrogen storage potential around the identified reusable infrastructure and which CO_2 emitters and potential hydrogen users could benefit from the reuse of this infrastructure;
- To perform economic assessments of reuse compared to new build for some specific case studies;
- To identify remaining technical challenges and mitigation options associated with the reuse of infrastructure for CCS and hydrogen projects.

The overall idea is to provide at high-level fact-based results (technical and cost) to inform the EU policy debate.

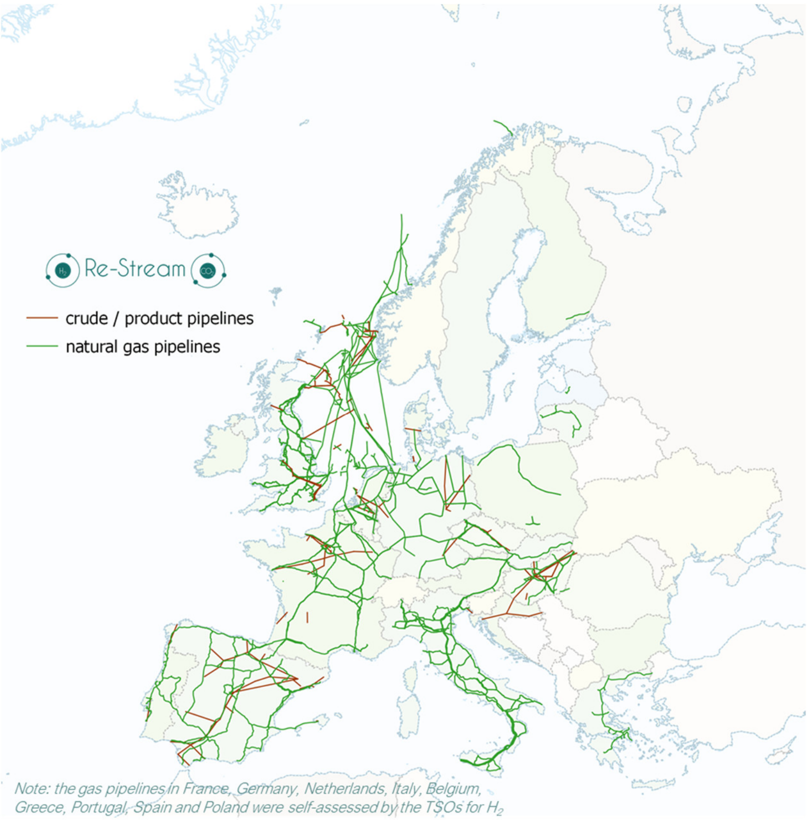
The term infrastructure, in this report, is mostly used for onshore and offshore pipelines.

Figure 1 - Re-Stream approach



All in all, 65 pipeline operators participated in the Re-Stream study, providing data that could be analysed within the Re-Stream project for approximately 58,000 km of pipelines[1] (+24,200 km assessed by operators themselves as suitable for H_2 reuse[2]) representing half of the total offshore pipeline length and approximately 30% of the onshore oil and gas pipelines.[3] Some operators provided data for all their pipelines while some others provided data for the pipelines that could become available soon. The length covered in the Re-Stream project is a good sample of the oil and gas pipeline network in Europe.

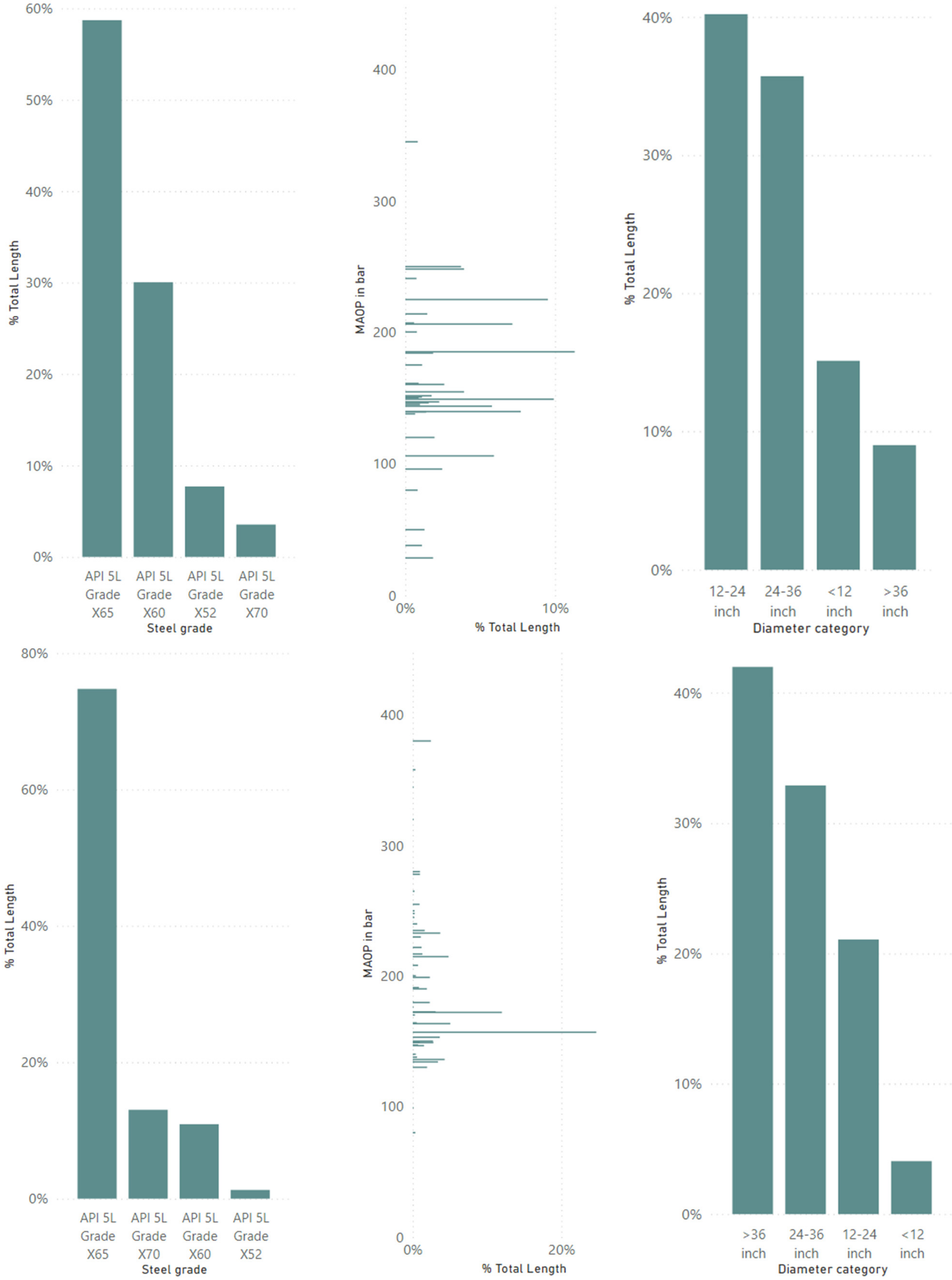
Figure 2 – Crude / product and gas pipelines considered in the Re-Stream study



Pipelines have different characteristics and as such might not requalify to transport all fluids in all phases. Figure 3 and Figure 4 below show the distribution of characteristics onshore and offshore.

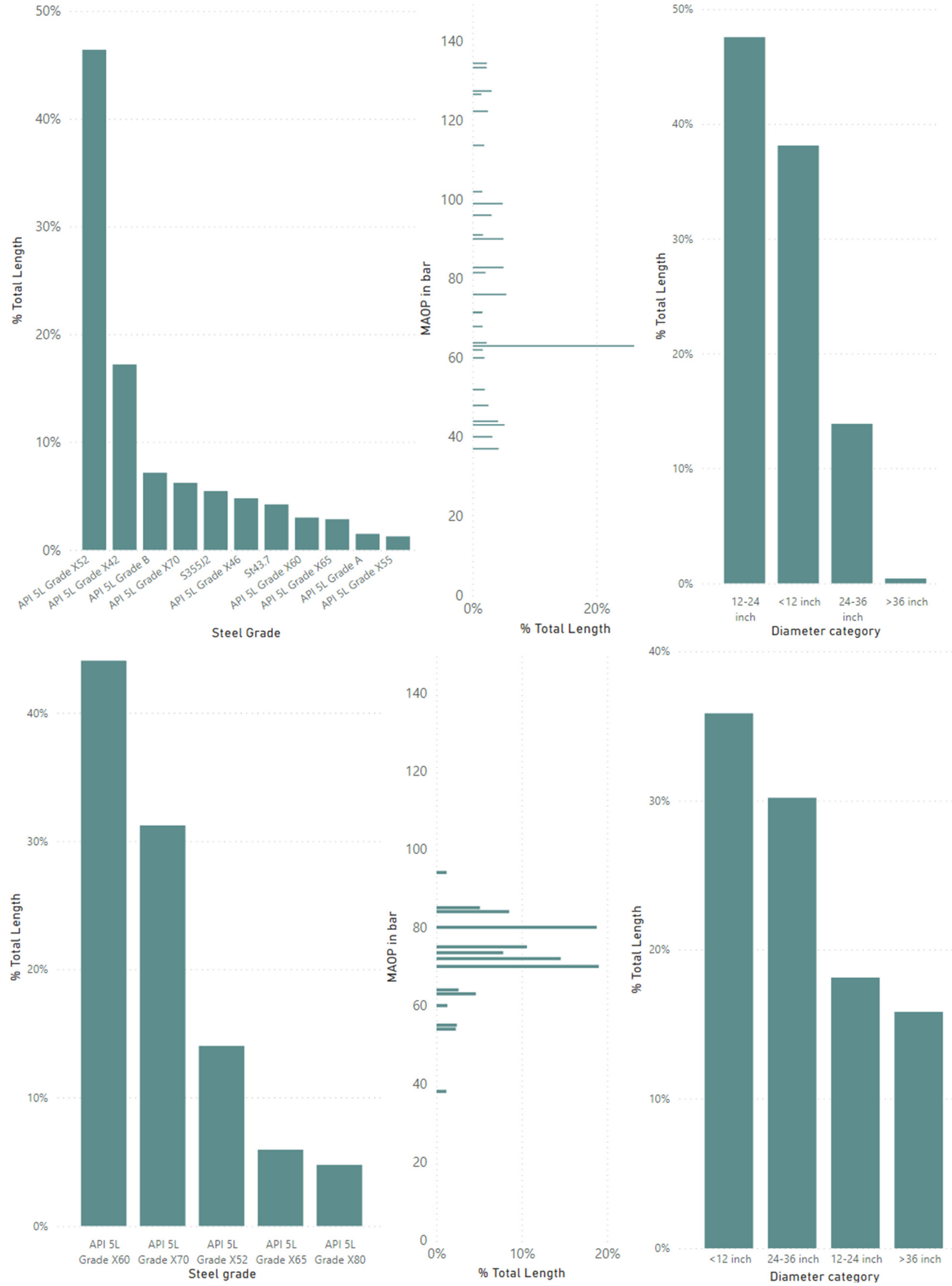
[1] 28,800 km of onshore gas pipelines / 12,900 km of crude/product onshore pipelines / 16,300 km offshore pipelines of which 13,570 km of gas pipelines
[2] Several operators that provided data to the Re-stream study have been / are assessing internally the reusability of their pipelines for H_2 and CO_2. Results from the Re-stream study should not prevail on operators' results considering the operators have access to more detailed data than the Re-stream team.
[3] For onshore gas pipelines, the data collection focused on the pipelines that may become available for transport of other products than gas in the next 20 years. Offshore, data were collected for all pipelines.

Figure 3: Distribution of materials of construction, Maximum allowable Operating Pressures (MAOP) and external diameters for offshore oil (incl. condensate) pipelines (top graphs) and offshore gas pipelines (bottom graphs) – Only material representing more than 1% of the length appear on the graphs. Total length top graphs = 3,300 km- Total length bottom graphs = 13,000 km



Source: data provided by IOGP members, Carbon Limits Analysis

Figure 4: Distribution of materials of construction, Maximum allowable Operating Pressures and external diameters for onshore crude/product pipelines (top graphs) and onshore gas pipelines (bottom graphs) – Only material representing more than 1% of the length appear on the graphs. Total length top graphs = 12,900 km- Total length bottom graphs = 28,800 km



Source: data provided by CONCAWE and ENTSOG members, Carbon Limits Analysis

An initial screening was carried out and pipelines were categorised in 3 categories:

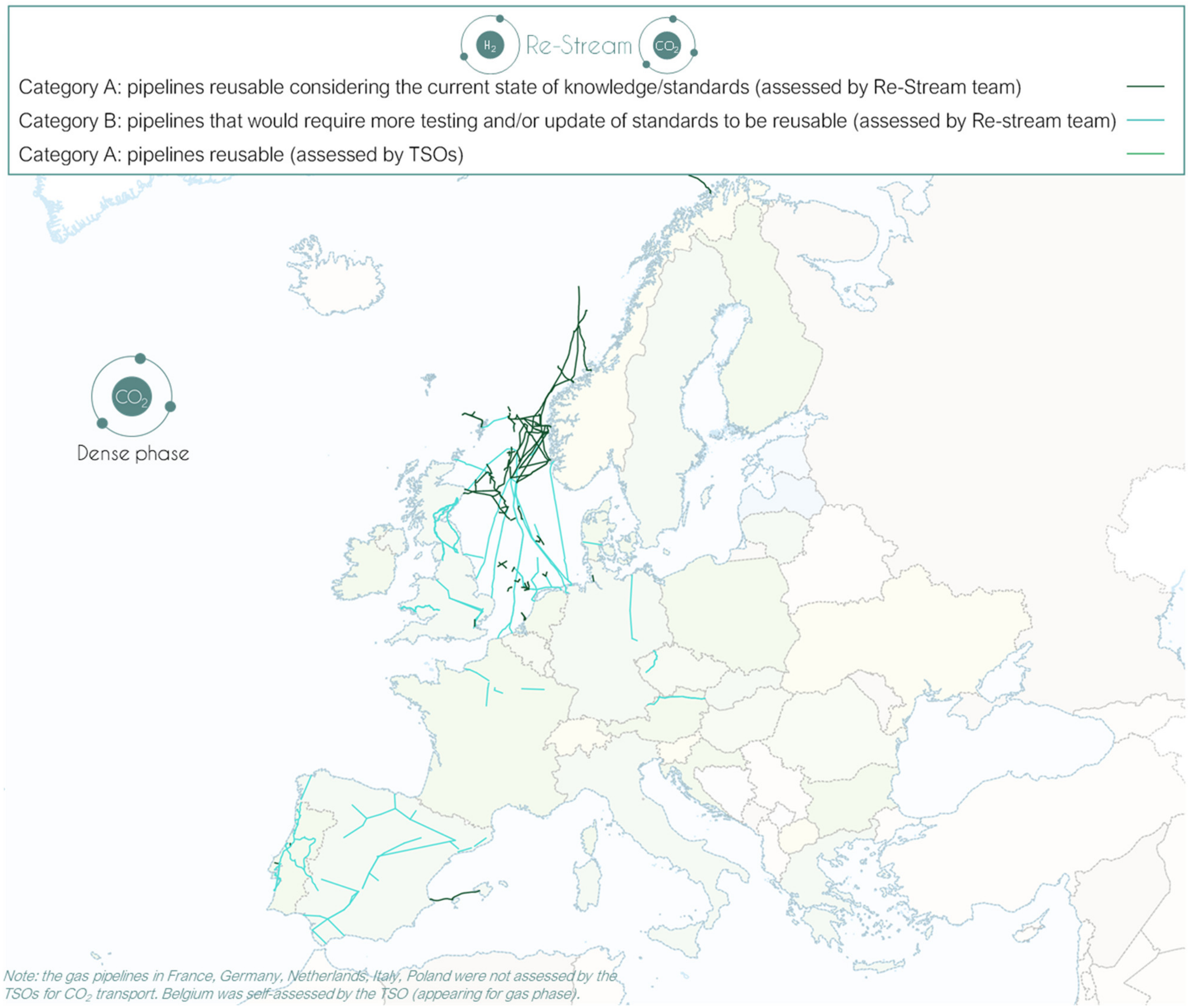
A. The pipelines reusable considering the current state of knowledge/standards.
B. The pipelines that would require more testing and/or update of standards to be reusable.
C. The pipelines not reusable.

Some operators have self-assessed their pipelines and those falls in Category A: pipelines reusable.

Categories A and B pipelines still require a proper requalification process (including but not limited to a more detailed integrity assessment of the pipeline) to finally confirm their reusability for H_2 or CO_2 but are promising pipelines for reuse.

Results for CO_2 transport in dense phase, gas phase and hydrogen transport are available respectively on Figure 5, Figure 6 and Figure 7.

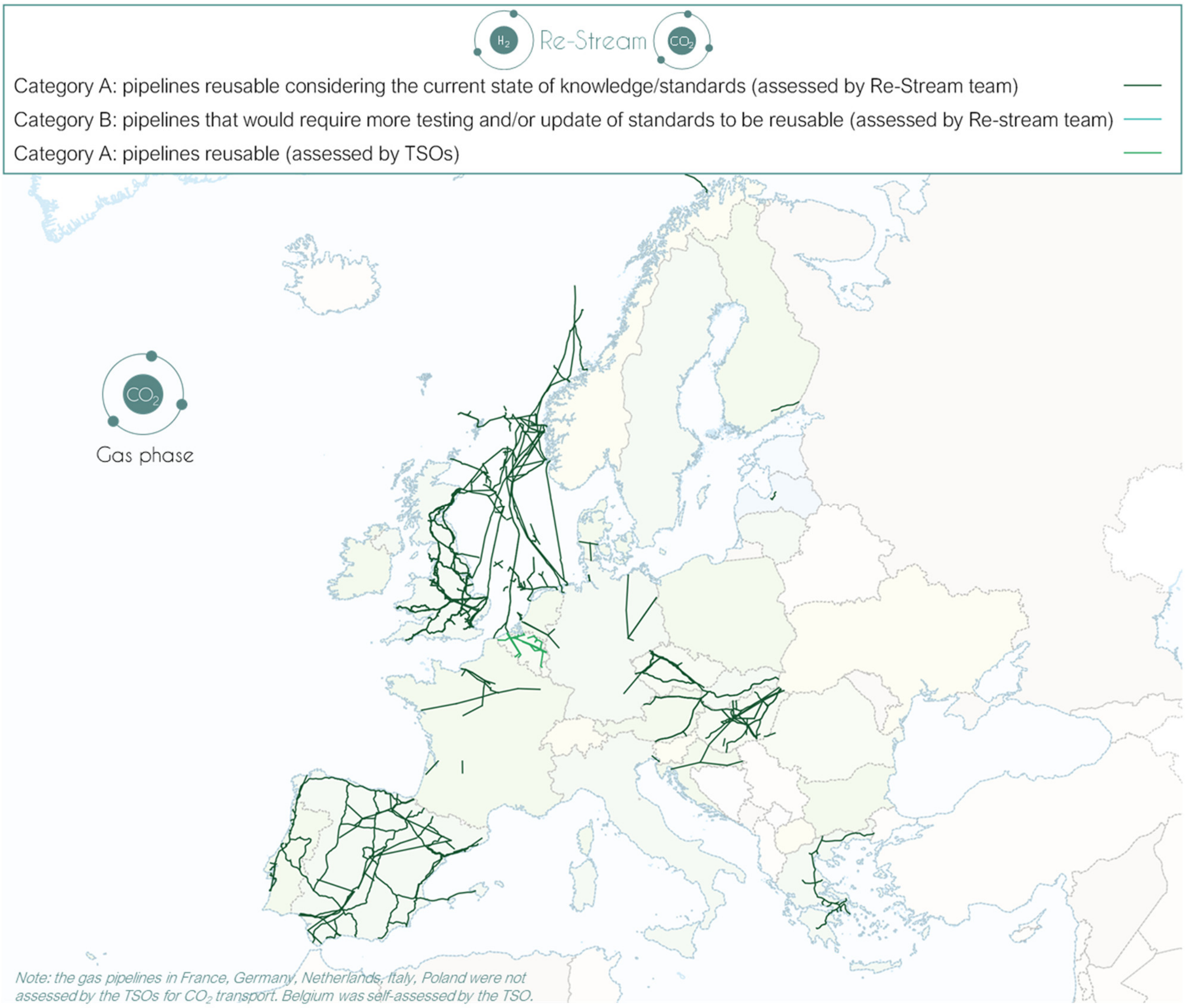
Figure 5 - Re-Stream assessment of reuse of oil and gas pipelines for CO_2 transport in the dense phase



Source: data provided by pipeline operators, Re-Stream team analysis

- CO_2 transport in dense phase is possible in more than half of the offshore pipelines considering the current state of knowledge/standards. An additional 40% of the offshore length would require more testing, analyses and/or update of standards to be reusable.
- A very small portion of the onshore pipelines would be reusable for CO_2 transport in dense phase considering the current state of knowledge/standards. Approximately one quarter of the onshore length could be reusable provided positive results from more detailed analyses and/or tests.

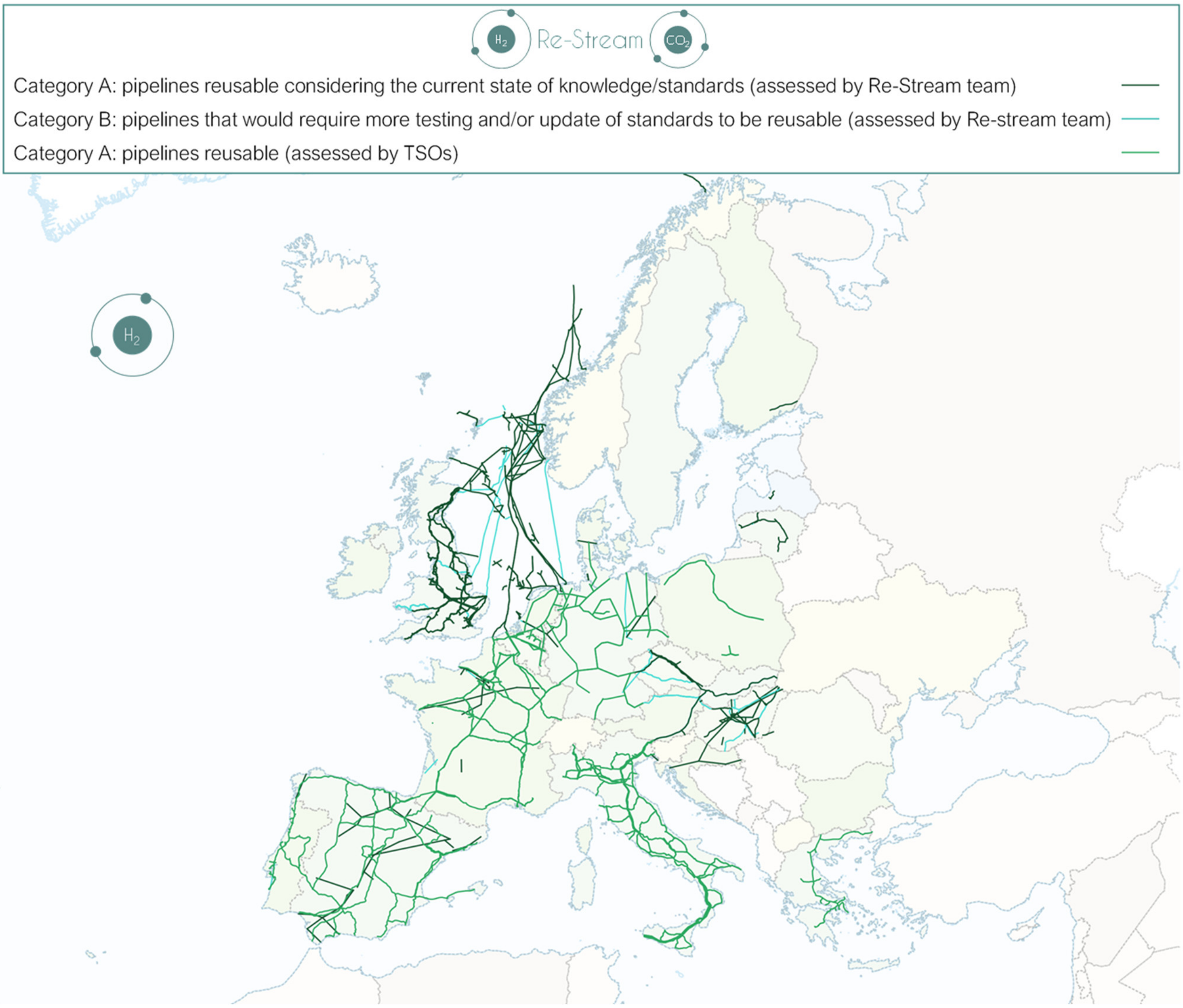
Figure 6 - Re-Stream assessment of reuse of oil and gas pipelines for CO_2 transport in the gas phase



Source: data provided by pipeline operators, Re-Stream team analysis

There are no showstoppers identified for transporting CO_2 in the gaseous phase in the existing onshore and offshore pipelines.

Figure 7 - Re-Stream assessment of reuse of oil and gas pipelines for 100% H_2 transport



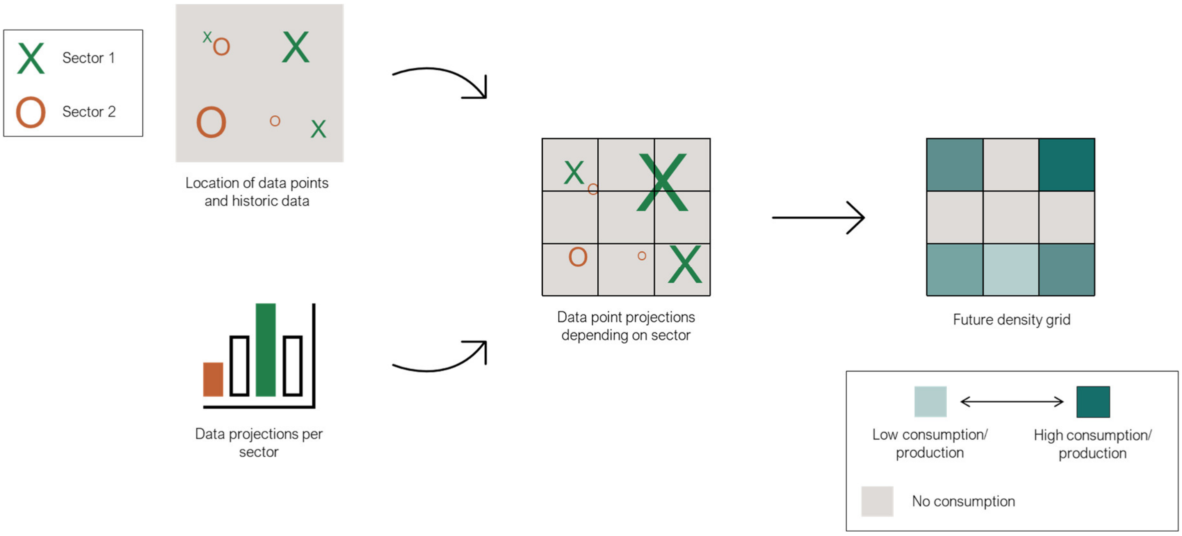
Source: data provided by pipeline operators, Re-Stream team analysis

- Most of the offshore pipelines can be reused for H_2.
- Onshore, close to 70% of the pipeline total length can be reused considering the current state of knowledge/standards. The remaining length of the pipelines is promising for reuse but would require more testing and/or update of standards to be reusable. None of the pipelines analysed can be categorically excluded from reuse as of today.

It is noteworthy that for the pipelines assessed to be reusable considering the current state of knowledge/standards, pipeline requalification processes should still be undertaken, and testing might be needed. Indeed, as mentioned earlier some criteria could not be considered for this initial screening. Running ductile fracture requirements for dense phase CO_2 pipelines, fatigue crack growth for H_2 service, detailed integrity status of the pipeline and timing (date of availability of the pipeline for other use) are some of the critical factors to be evaluated as a first step of the pipeline requalification process.

To identify business opportunities, a source (production site/storage) sink (storage / consumption) matching was carried out. The most probable locations of sources / sinks were predicted based on current trends and access to physical resources (see methodology in Figure 8).

Figure 8 - Methodology for upscaling of the mapping grid to produce a density map of future volumes in a given area



Source: Carbon Limits

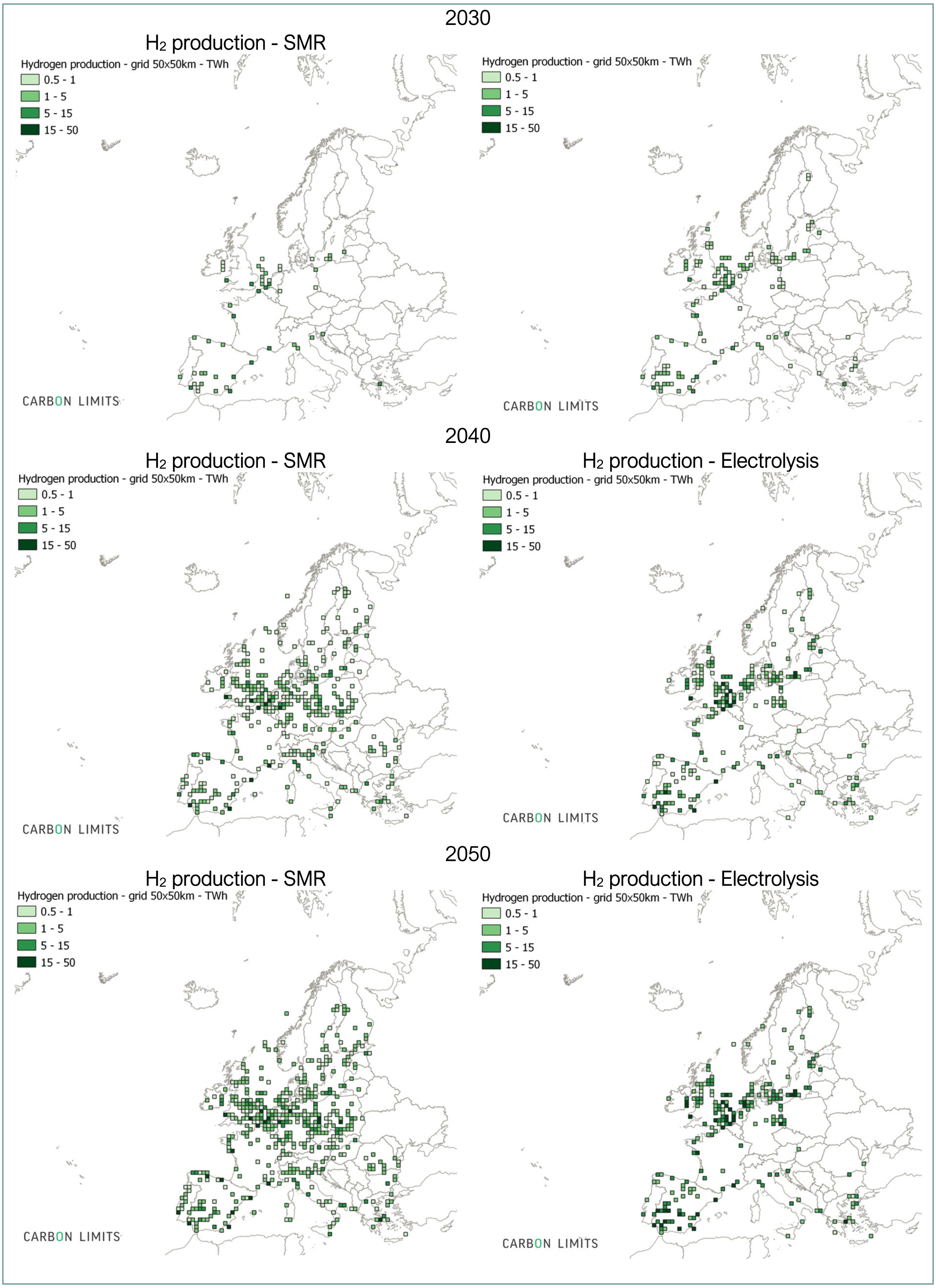
The following grids were created:

- H_2 production grids in 2030 /2040/2050 (see Figure 9),
- H_2 consumption grids in 2030 /2040/2050 (see Figure 10) and,
- CO_2 sources in 2030 /2040/2050 (see Figure 12).

Two storage maps were also created:

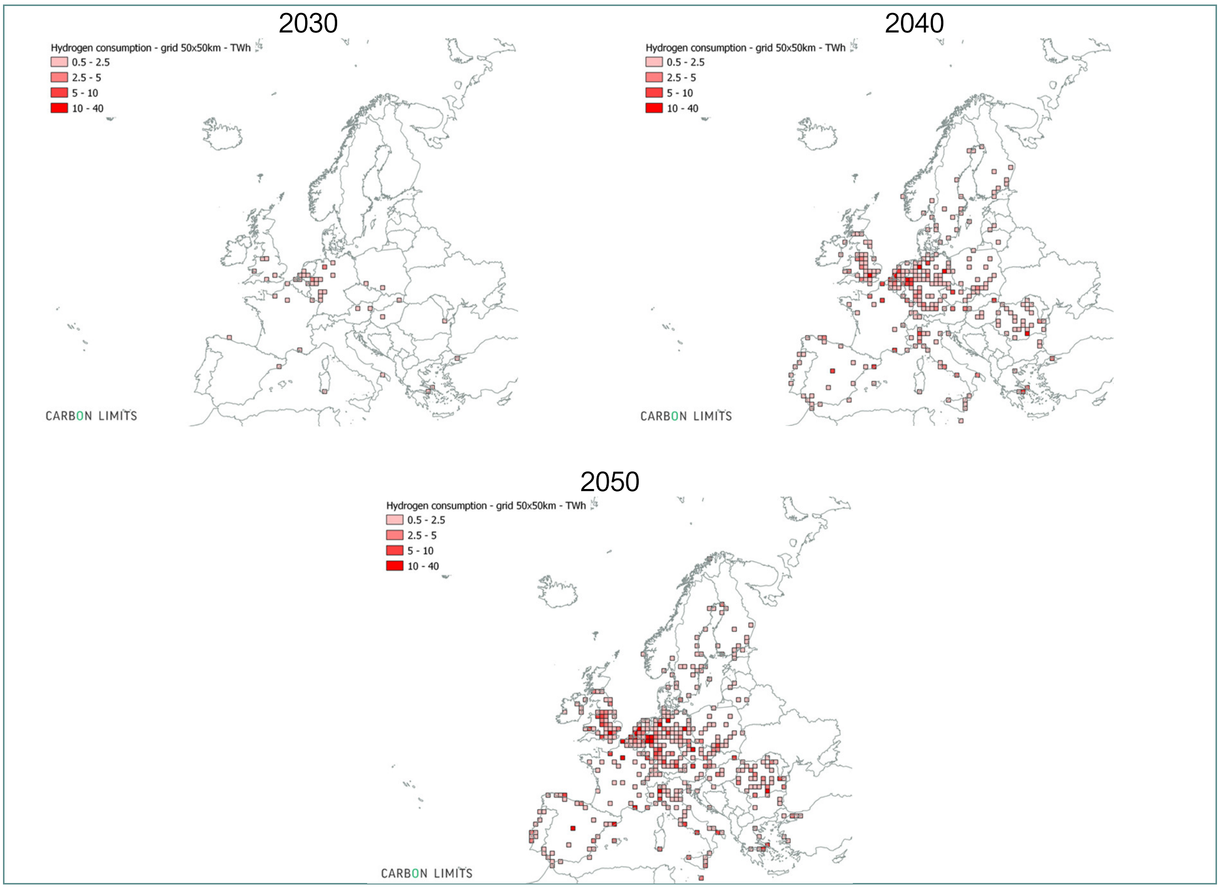
- A H_2 storage map (see Figure 11) and,
- A CO_2 storage map (see Figure 13).

Figure 9 – Maps of hydrogen production density by year for SMR and Electrolysis from renewables scenarios. Production density = volume of production facilities within a 50x50 km grid cell.



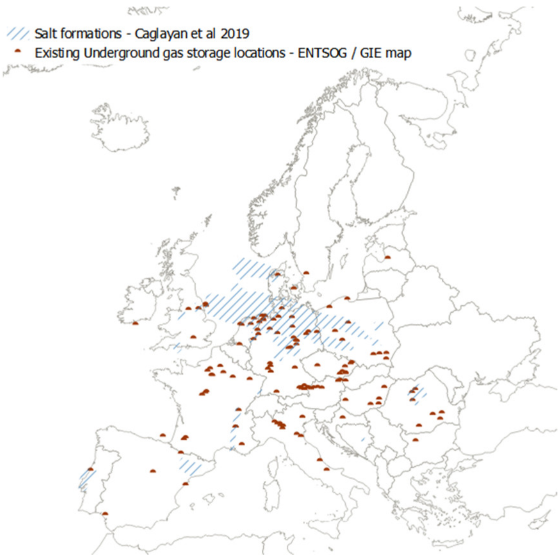
Source: Carbon Limits analysis

Figure 10 – Maps of hydrogen consumption density by year where consumption density = volume of consumption facilities within a 50x50 km grid cell.



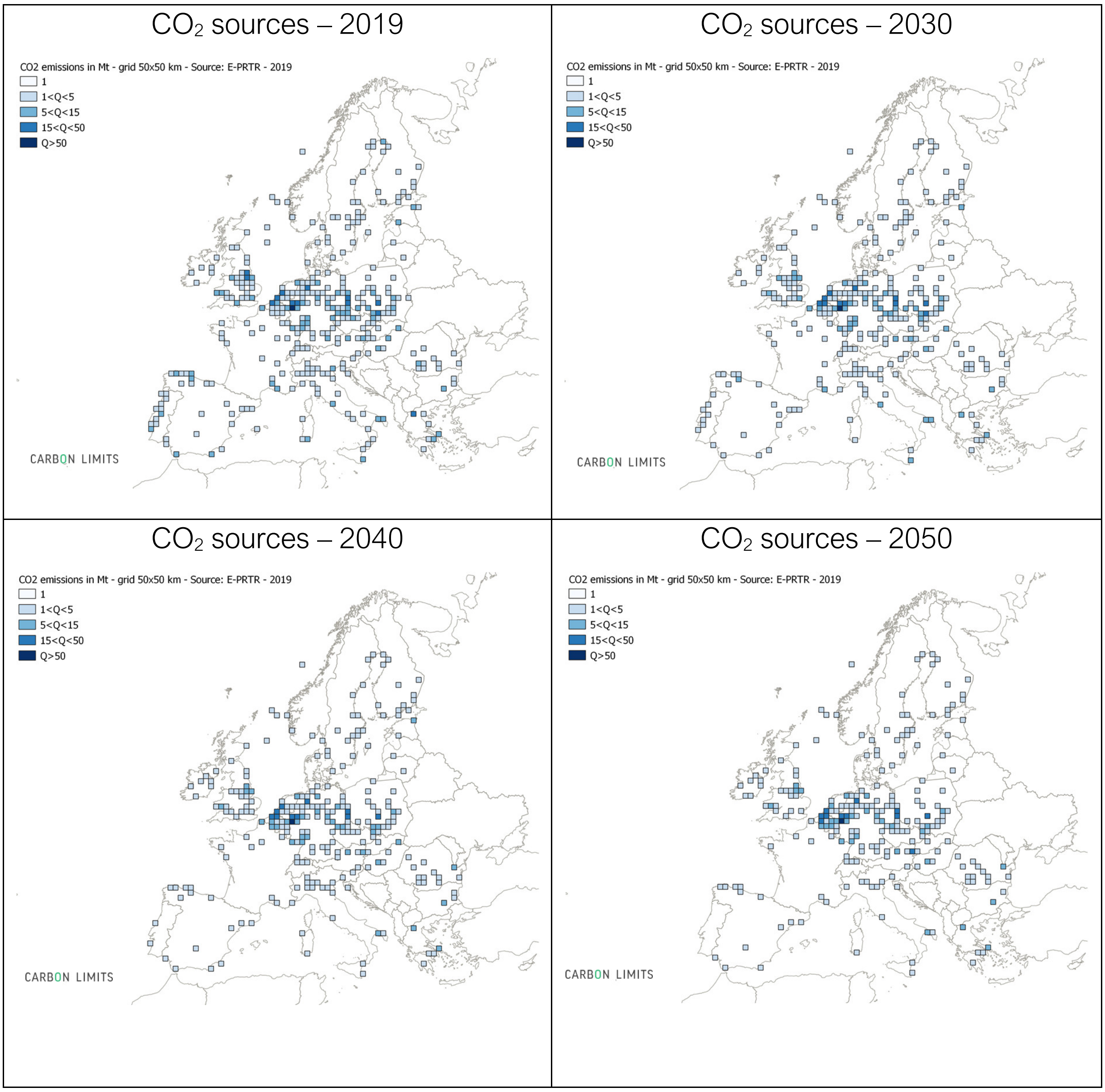
Source: Carbon Limits analysis

Figure 11 - Location of potential hydrogen storage in Europe



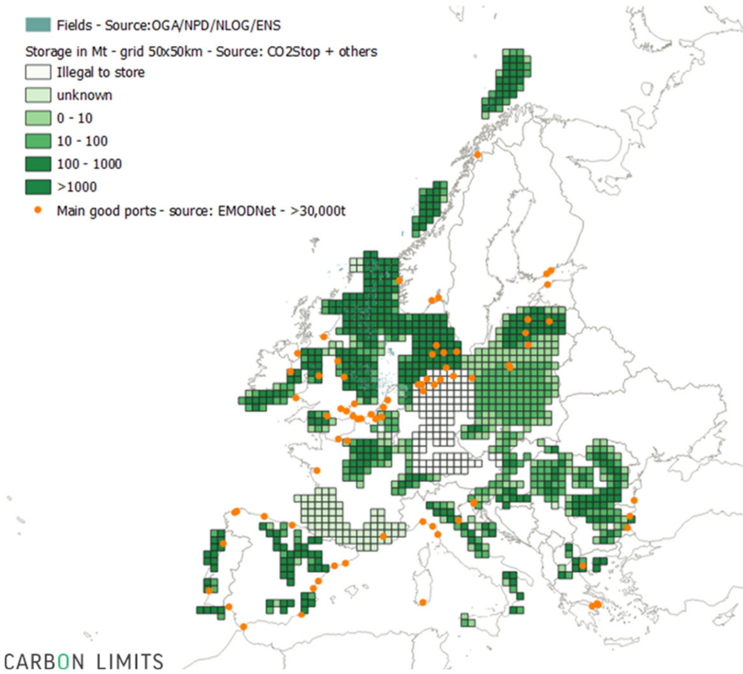
Source: Carbon Limits based on Caglayan et al 2019 and ENTSOG / GIE map

Figure 12 - CO_2 emission sources - density grid 50x50 km - 2019 / 2030 / 2040 / 2050



Source: Carbon Limits analysis

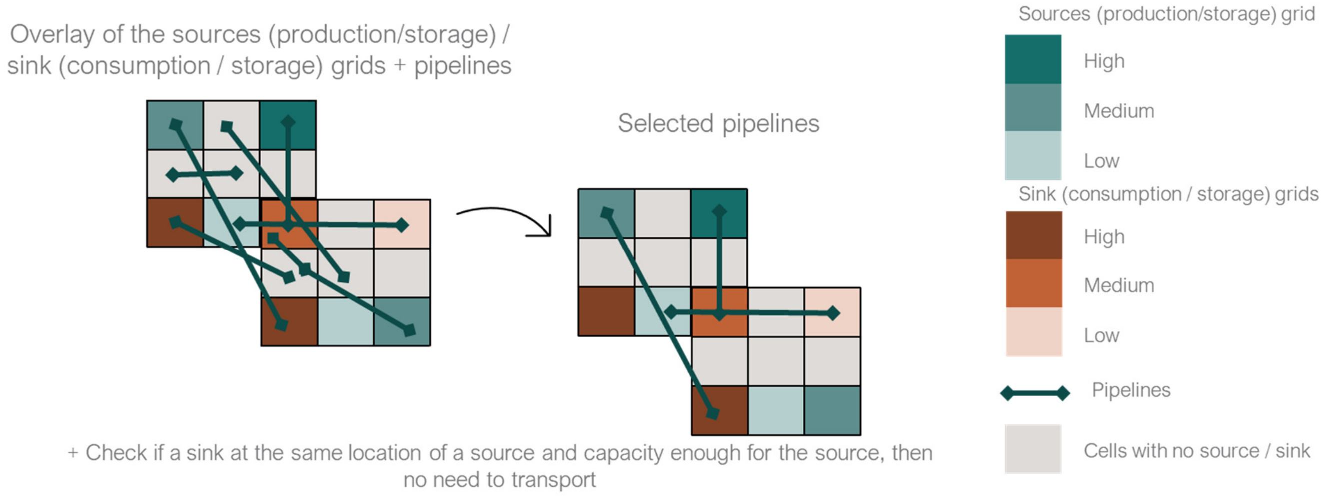
Figure 13 - CO_2 storage locations - density grid 50x50 km and ports



Source: Carbon Limits analysis

To identify business opportunities, a source (production site/storage) sink (storage / consumption) matching exercise was carried out overlaying the source/sink and pipeline layers. A minimum pipeline length for business opportunities was calculated.

Figure 14 - Illustration of the approach carried out to identify case studies



Source: Carbon Limits

There are some clear opportunities:

FOR CO_2

- A minimum of around 70% of the existing offshore pipeline length is relevant for CO_2 transport as many of the long pipelines are linking harbours to CO_2 storage locations.

- Regarding onshore pipelines, a minimum of 20% of the pipeline length shows some business opportunities linking sources to sinks (harbours or onshore storage sites). It is very likely that this proportion would grow significantly if the automatic approach undertaken in the study would have allowed for only part of the pipelines to be reused or for pipeline connections to be better considered.

FOR H_2

- A SMR/ATR production scenario gives a higher degree of obvious business opportunities compared to an electrolysis production one as SMR/ATR production locations are linked to the current gas infrastructure.
- Depending on the demand/production locational assumptions, the minimum reusable offshore pipeline length for hydrogen is between 2% and 25%.
- With regards to onshore, based on the demand/production locational assumptions taken in this study, the minimum reusable pipeline length for hydrogen is 20% to 30%. As for CO_2, it is very likely that this proportion would grow significantly if the automatic approach undertaken in the study would have allowed for only part of the pipelines to be reused or if pipeline connections, the security of supply and the benefits of an interconnected market had been considered[4]. According to the operators, the EU network is so well meshed that current infrastructures are likely to be enough to connect production with demand with only the last miles that would need to be added.

Among the cases identified, 6 cases were studied in more details. The six cases are detailed in Table 1 and Table 3. For those cases, no technical showstoppers were found at this stage. An economic assessment was performed comparing a new built option to the reuse option. The boundaries of the assessment are detailed in Figure 15 for CO_2 and in Figure 16 for H_2. The present value of cost was calculated following Equation 1. The results are available in Table 2 and Table 4.

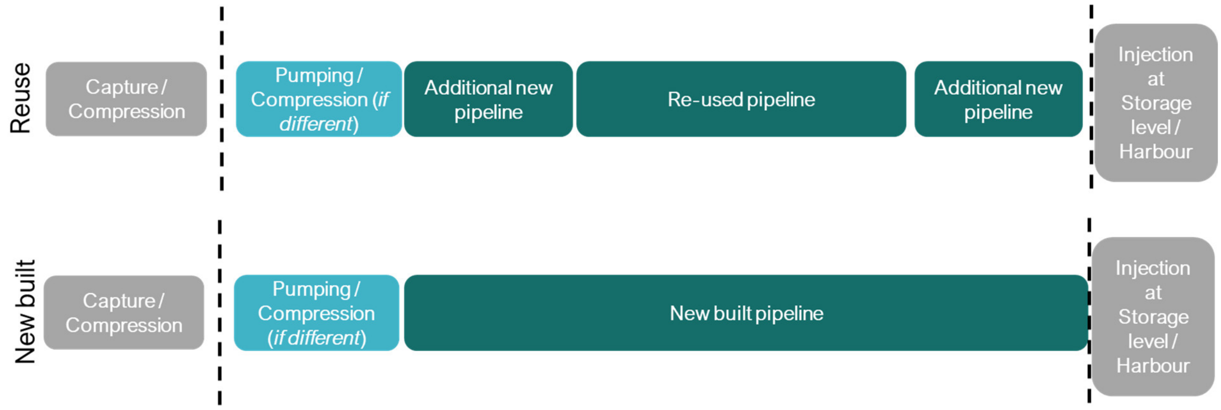
[4] Indeed, several producers connected to several consumers is a better model for the development of a market and to ensure security of supply.

Table 1 - CO_2 selected cases

Class of case	Offshore dense phase transport to saline aquifer or depleted field	Onshore gas phase transport to harbour	Onshore gas phase transport to onshore storage
Case name	1 - Fulmar - St Fergus (UK)	2 – Paris – Port Jérôme (FR)	3 - Setúbal – Leiria (PT)
Current operator	Shell	Trapil	REN
Current Fluid transported	Gas	Oil	Gas
Dimension (D/L)	20” – 289 km	20” – 170 km	28” - 68 km
CO_2 source	A possible ACORN project extension	Around Paris Waste to energy Cement Other 1.6 $MtCO_2/y$	Power plants 1.2 $MtCO_2/y$
CO_2 storage - Depleted field / Deep Saline aquifers	Several formations including Balder – theoretical storage capacity: 3.3 $GtCO_2$	Port Jérôme	Lusitanian – 0.1 $GtCO_2$
Location			

Note: Case 3 - The Portuguese gas network is set to be the future H_2 national backbone, in accordance with the national energy policy. Any evaluation for CO_2 management purposes is at this stage only for evaluation purpose.
Source: Re-Stream team analysis

Figure 15 - System boundary for CO_2 cases



Equation 1 - Present value

$$PV = CAPEX + \sum_{1}^{n} \frac{OPEX}{(1+DR)^n}$$

Where:

$n = total\ period\ duration\ (project\ lifetime)$

$DR = discount\ rate$

Table 2 - CO_2 cases results

		1 - Fulmar - St Fergus (UK)	2 - Paris - Port Jérôme (FR)	3 - Setúbal - Leiria (PT)	
Scenario (Capacity limited by)		Pipeline	Pipeline	Producer	Pipeline
Compression/pumping		not included	not included	included	not included
Capacity	Mtpa	8.9	1.5	1.2	5.2
Re-use total cost	MEUR	125	70	80	90
New build total cost	MEUR	745	260	170	190
Savings	MEUR	620 (83%)	190 (73%)	90 (53%)	100 (53%)
	MEUR/km	2.1	1.0	0.9	1.0

Note: When compression/pumping are the same between the reuse and new build cases, it was chosen not to consider their costs in order to only assess the actual cost difference between scenarios

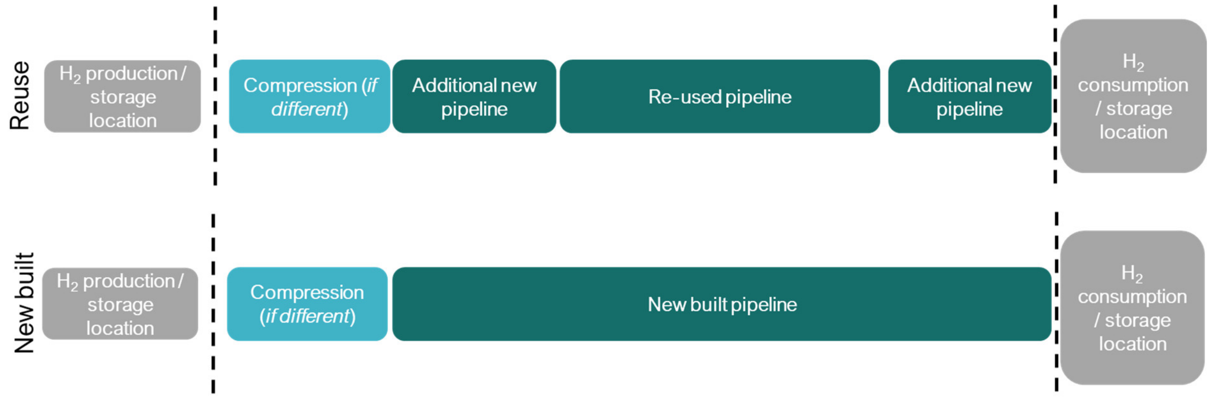
Source: Re-Stream analysis

Table 3 - H_2 selected cases

Class of case	Offshore transport from wind farm to H_2 consumer	Onshore transport from solar farm or wind farm / LNG terminal/Harbour to H_2 consumer	Onshore transport from solar farm or wind farm / LNG terminal/Harbour to H_2 consumer
Case name	4 – P15 –D – Maasvlakte (NL)	5 – Almodovar – Merida (ES)	6 – Feeder 13 (UK)
Current operator	TAQA Energy	Exolum	National Grid
Current Fluid transported	Gas	Product	Gas
Dimension (D/L)	26" – 40 km	8 5/8" - 215 km	18" / 42" – 240 km
H_2 producer	Wind farms: Hollandse Kust Zuid Holland III – IV / Hollandse Kust Zuid Holland I - II OWF Luchterduinen – 8.8 TWh/y	Solar – 4 TWh	St Fergus – 1.4 TWh/y
H_2 consumer	Rotterdam / to be distributed from there	Industrial clusters: Refinery / Fertilizer	Edinburgh area Airport Industries 1.1 TWh/y
Location			

Source: Re-Stream team analysis

Figure 16 - System boundary for H_2 cases



Equation 2 - Present value

$$PV = CAPEX + \sum_{1}^{n} \frac{OPEX}{(1 + DR)^{n}}$$

Where:

$n = total\ period\ duration\ (project\ lifetime)$

$DR = discount\ rate$

Table 4 - H_2 cases results

		4 - P15-D - Maasvlakte (NL)		5 - Almodovar - Merida (ES)		6 - Feeder 13 (UK)	
Scenario / Capacity limited by		Producer	Pipeline	Consumer	Pipeline	Consumer	Pipeline
Compression		included	not included	included	not included	included	included
Capacity	TWh/y	8.8	22.1	0.7	2.3	1.1	12.5
Re-use total cost	MEUR	35	30	60	55	120	260
New build total cost	MEUR	155	105	300	295	360	700
Savings	MEUR	120 (76%)	75 (72%)	240 (80%)	240 (82%)	240 (67%)	440 (63%)
	MEUR/km	2.6	1.6	1.1	1.1	0.9	1.7

Note: When compression are the same between the reuse and new build cases, it was chosen not to consider its costs in order to only assess the actual cost difference between scenarios

Source: Re-Stream analysis

The economic assessment of those cases confirmed the strong potential for cost reduction involving reuse of pipelines compared to their new build options. For both CO_2 and H_2 transport, 53% to 82% of cost reduction can be achieved with around 2 MEUR/km cost reduction for offshore cases and 1 MEUR/km for onshore cases. Those cost reductions are of particular importance in the initial phases of development of CCS and hydrogen infrastructure.