The Practical Potential for Gas Power with CCS in Europe in 2030

Final Technical Appendix

For:

The European Climate Foundation

Lead authors:
Harsh Pershad
Foaad Tahir

Element Energy Limited

with inputs from:
Chris Littlecott
Elise Attal

Green Alliance

28th March 2012

www.element-energy.co.uk

Caveat

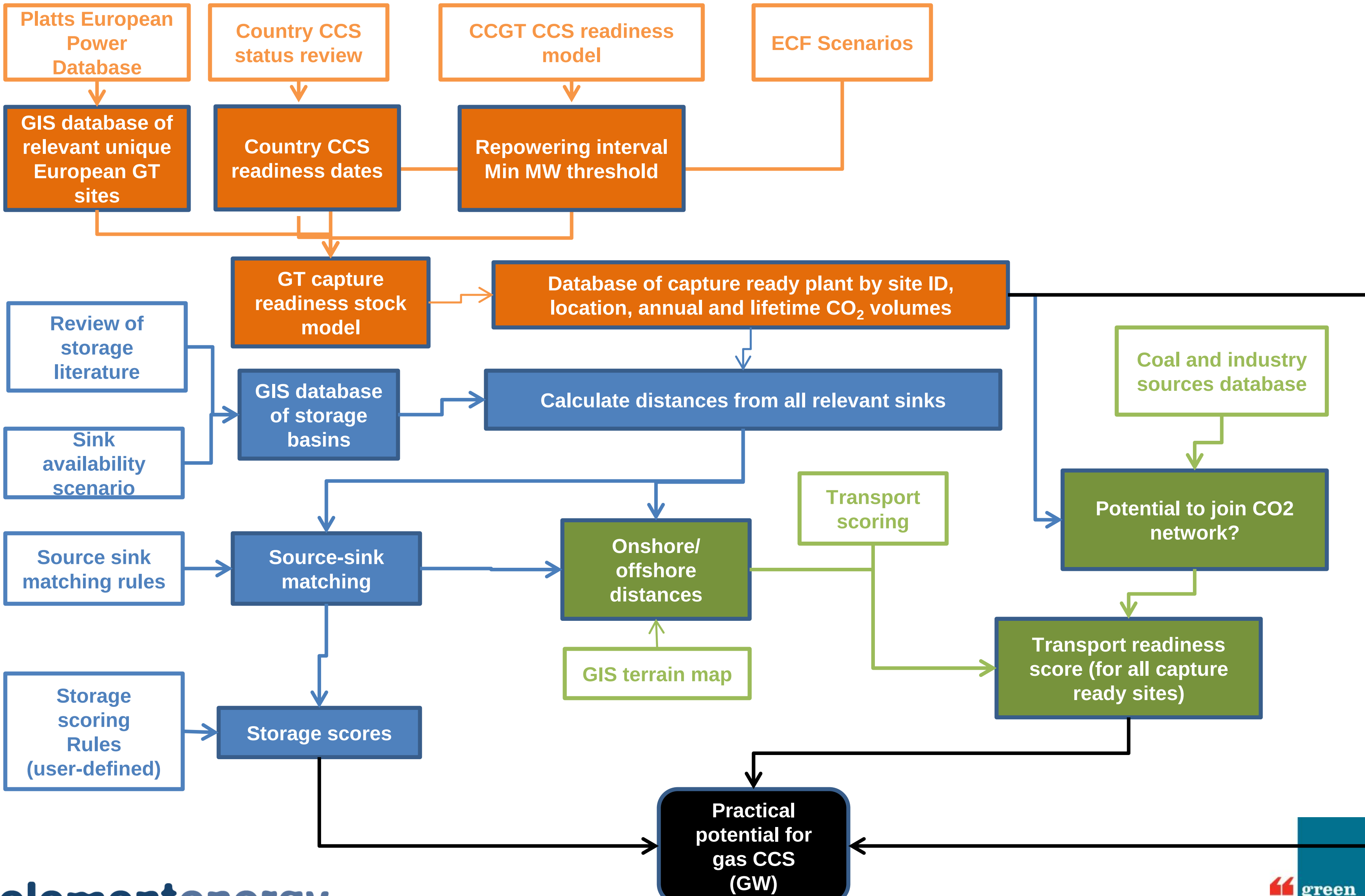
- While the authors consider that the data and opinions in this report are sound, all parties must rely on their own judgement and skill when using it.
- The authors do not make any representation or warranty, expressed or implied, as to the accuracy or completeness of the report.
- There is considerable uncertainty around the development of gas markets and CCS technology. The available data and models on sources and sinks are extremely limited and the analysis is therefore based around purely hypothetical scenarios. All models are limited by the quality and completeness of assumptions that go into these.
- The maps, tables and graphs are provided for high-level illustrative purposes only, and no detailed location-specific studies have been carried out.
- The authors assume no liability for any loss or damage arising from decisions made on the basis of this report.
- The views and judgements expressed here are the opinions of the authors and do not reflect those of ECF or the stakeholders consulted during the course of the project.
- The conclusions are expected to be most robust when considering EU27+2 aggregated data. The input data have decreasing reliability at lower levels of aggregation (e.g. national, where only broad trends would be relevant). “Over-analysis” of country-specific and site-specific assumptions is strongly discouraged.

Appendix – Contents List

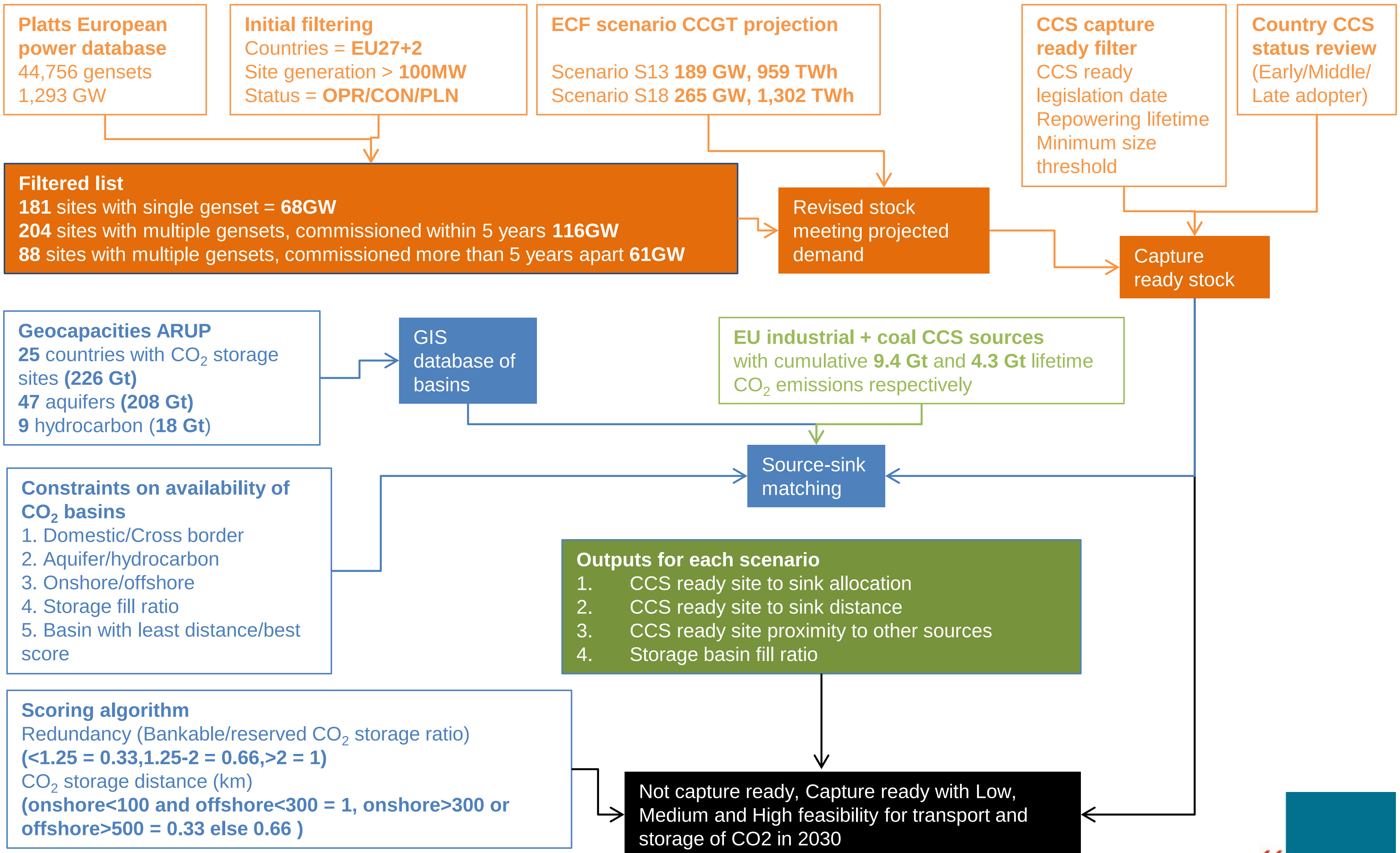
Existing models for capture readiness and source-sink matching have been adapted to assess the realistic potential for gas CCS in Europe

- The eventual deployment of CCS technology will depend upon many techno economic issues as well as consideration of practical constraints and barriers. For example, investors will require a business case that incentivises the construction of new gas CCS plant, or the retrofit of CCS technology to existing plant.
- This project aims to explore the practical issues around capture readiness, CO_2 storage feasibility and the availability of CO2 transport solutions. Other issues of relevance to the business case (load factor, despatch, market frameworks, technology performance etc) remain out of the scope of this initial analysis.
- The 2030 timeframe has been used as the reference point for this analysis. This date has both policy and practical relevance. For the former, European policy makers are currently considering the 2030 time horizon in respect to future targets for decarbonisation or low carbon technologies. For the latter, 2030 is sufficiently close for it to have influence on contemporary investment decisions, while the size and distribution of the existing CCGT fleet is of relevance for considerations of how and where CCS might be deployed.
- Beyond 2030, technology options expand while the modelling of changes to the existing CCGT fleet becomes less precise. Nevertheless, lessons learnt from the 2030 analysis will serve as useful pointers for discussion of options for CCS on gas in the period from 2030 to 2050.

High level architecture of model for investigating practical aspects of CCS readiness.



Detailed data and scenario inputs to the model and generated outputs



elementenergy

green alliance...

Modelling methodology

- A consolidated database of planned and operational CCGTs was developed based on the Platts European power database.
- The ECF S13 and S18 scenarios are used to project the gas CCGT stock in 2030 for EU27+ Norway and Switzerland.
- The date from which meaningful capture readiness legislation is implemented is selected on a country-by-country basis.
- From the interplay of forecast stock growth and the timing of meaningful CCS readiness adoption, the capture ready stock can be estimated for any given year.
- The storage literature is reviewed to develop a low resolution GIS database of theoretical CO_2 storage capacities.
- Multiple scenarios were developed for levels of bankable theoretical storage (%) and reserved storage for coal and industry CCS.
- Existing peer reviewed source-sink matching algorithms were adapted for this project. These ensure each source is connected to a storage basin with sufficient capacity. Some storage basins can be connected to multiple sources. Scoring relates to distance between source and basin and the share of storage already reserved. The distance is split into onshore and offshore using GIS terrain maps.
- In some scenarios, the distance metric is replaced if there is potential to join a CO_2 network due to proximity to industry and coal CO_2 sources.
- This final score is used to rate each capture ready site as having high, medium or low feasibility for CO_2 transport and storage in the given scenario.
- High scoring plants are considered to have practical potential for CCS.

Appendix – Contents List

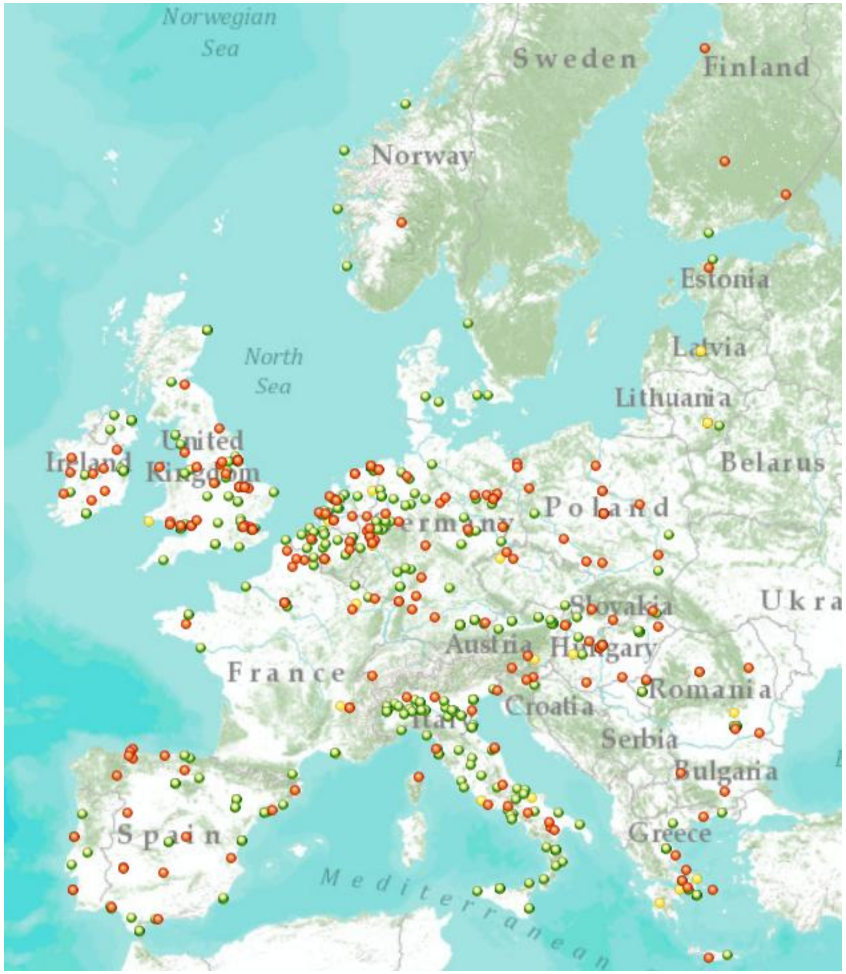
Projections of gas demand in 2030 are used to extrapolate the scale and distribution of the gas fleet by country

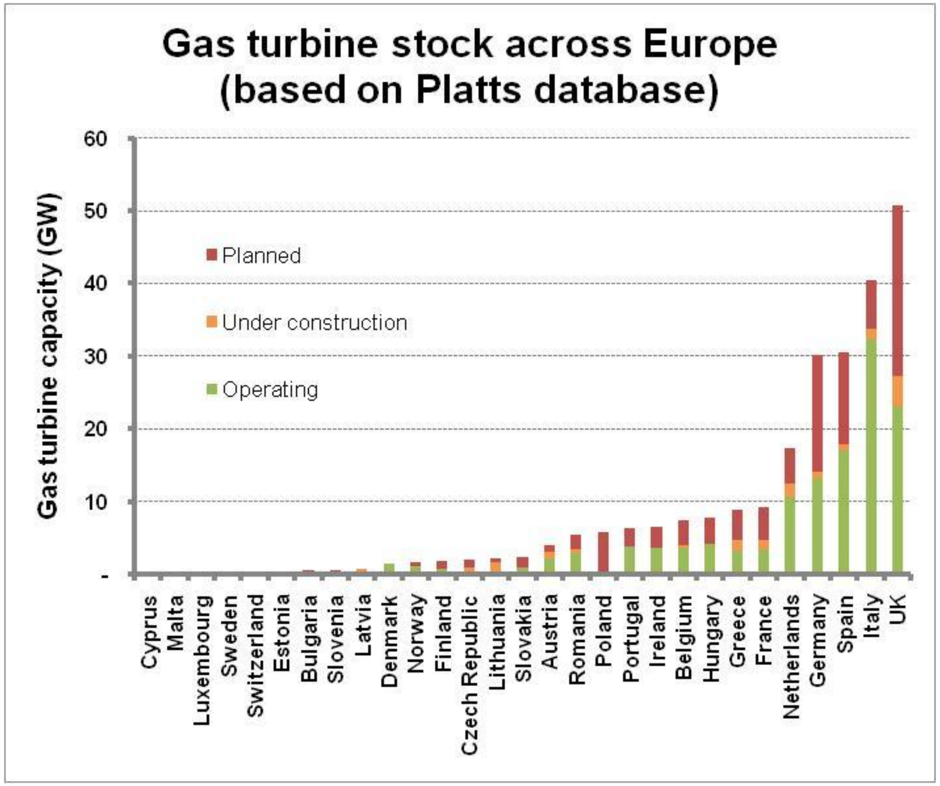
- In order to investigate the feasibility of CCS readiness in 2030, the stock of gas CCGT sites needs to be defined.
- The Platts database provides the information around size, location and year of commissioning for stock that is currently in operation, under construction or being planned.
- The total EU stock and country breakdown are based on ECF projections for different levels of future gas demand, with a high and a low stock level serving as the two baseline levels being modelled.
- These projections are then translated into a site based stock for each country by using Platts database.
- Existing CCGT plant locations are used, and future demand growth is accommodated where required by repowering existing plants, assumed to happen every 20 years.
- While future CCGT locations may alter to reflect different prioritisations (including for easier access to CO_2 storage and transport), for the purposes of the modelling existing and planned CCGT locations were used.
- The use of new as-yet-unidentified alternative greenfield or brownfield locations for new CCGT investments is not modelled.

Platts European power database provides initial data

- The Platts European power database provides detailed information about size, location, fuel, status and commission year for 8,730 generation plants across EU of which 8,105 are operating, under construction or being planned in 4,443 unique sites and amount to 291GW total capacity
- These generators vary in size from 0.003 – 1600 MW while the year of commissioning for plants at a same site differ from being the same to 73 years apart
- The data are first filtered to obtain sites with a single CCGT installed whose size is superior to 100MW, resulting in 181 sites and total generation capacity of 69GW
- The remaining sites, with multiple gensets, are filtered to obtain the sites where the commission dates of individual gensest differ by no more than 5 years and whose cumulative capacity is superior to 100MW, resulting in 204 sites and a total generation capacity of 119GW
- The remaining sites, with multiple gensets where the commission dates of individual genset differ by more than 5 years, are filtered to obtain the sites where individual genset size is superior to 100MW, resulting in 88 sites with 244 individual generators and total generation capacity of 62GW
- This gives a finalised list of 629 unique generating sites of which 617 are located in EU27+Norway and Switzerland (EU27+2) and have a total generation capacity of 245GW. The remaining 12 sites are in Albania, Bosnia-Herzogovina, Croatia, Macedonia and Serbia, and are not included in this analysis..

GIS database of existing, under construction and planned CCGT capacity above 100 MW in unique sites in EU27+2.





Operating Under construction Planned

ECF scenarios for 2030 are used to develop projections of the gas fleet at country level

- Two ECF scenarios are used to project the demand for gas CCGT in 2030:
  - S13 (low gas) = 189 GW / 959TWh
  - S18 (high gas) = 265 GW / 1302TWh

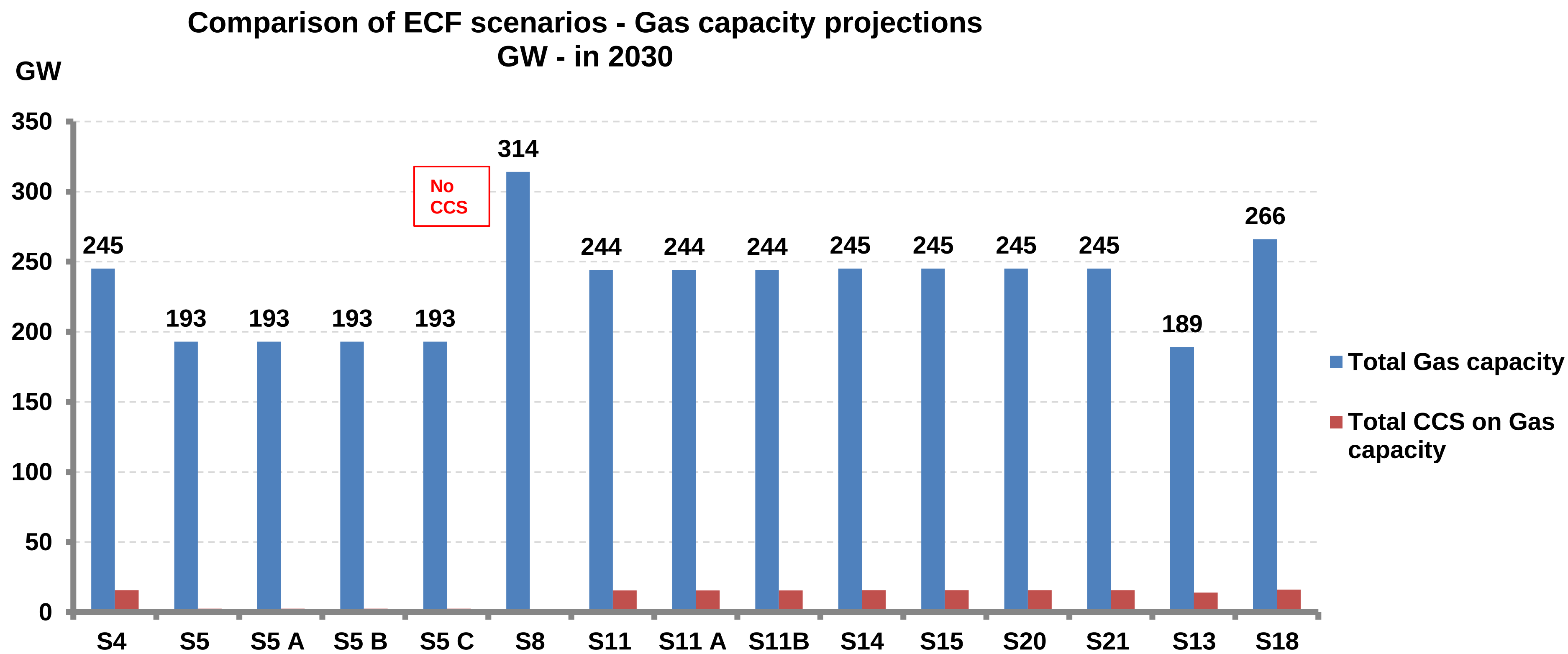
- These scenarios also define the gas CCGT capacity and generation at country level for EU27+2.

- The reduced Platts database is used to develop a stock that meets these projections at country level, assuming that existing operational plants are repowered to meet additional demand by 2030.

- For countries where total existing stock in 2030, based on Platts database, is insufficient to meet the ECF projected demand, the repowered sites are up sized to meet the required capacity.

- For countries where total existing stock in 2030 exceeds the ECF projected demand, based on Platts database, the sites due for repowering at a later date, as well as new build if needed, are removed to reduce stock to required capacity.

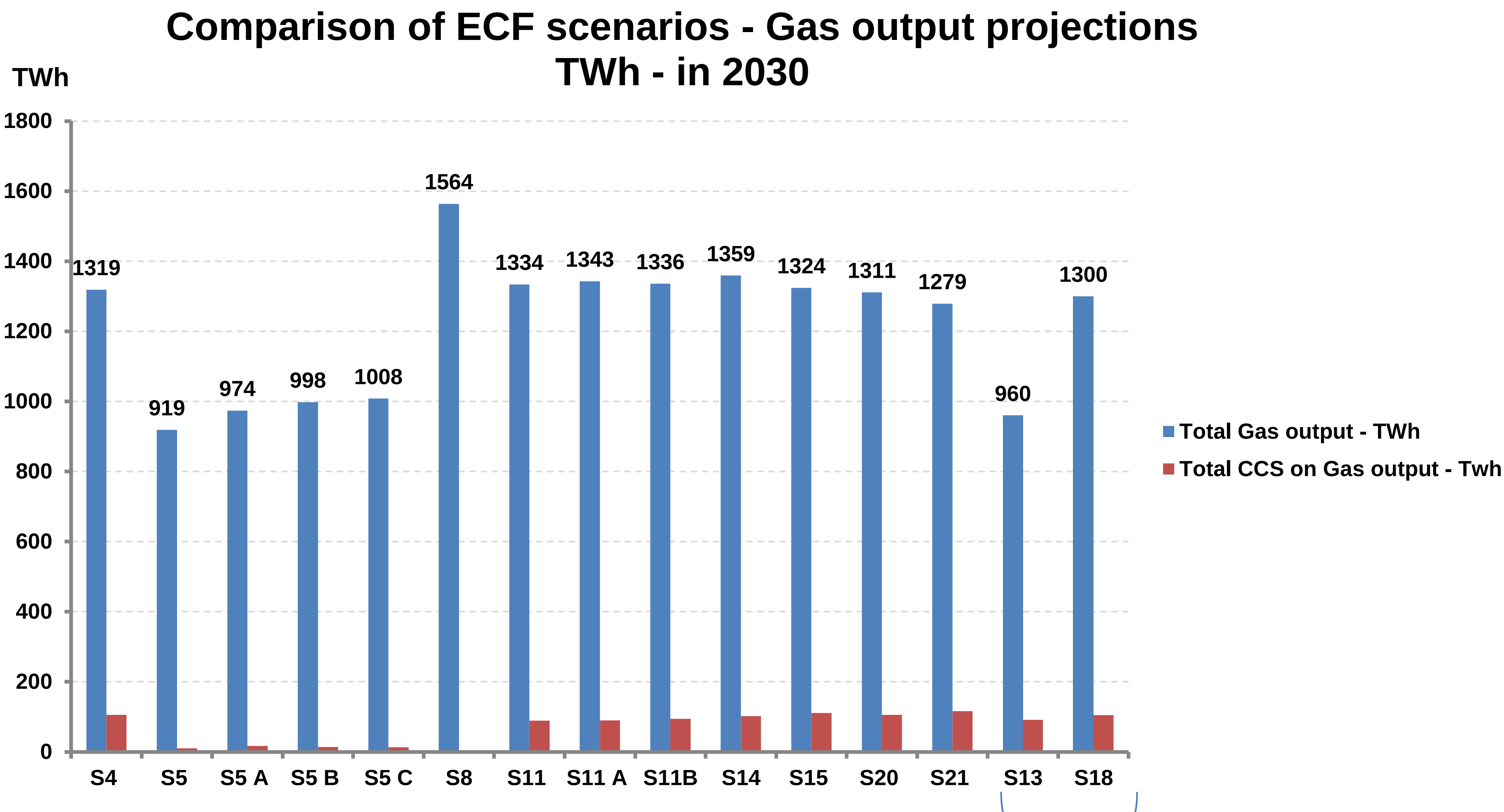
ECF scenarios show a range from 189-314 GW gas capacity in 2030, with gas CCS levels spanning the range 0-16 GW.



Above scenarios are based on the report *"ECF Power Perspectives 2030"*
http://www.roadmap2050.eu/attachments/files/PowerPerspectives2030_FullReport.pdf

Chosen scenarios:
S13 – Low gas = energy efficiency
S18 – High gas = older plant as backup.

ECF scenarios identify 960-1564 TWh electricity generated/yr in 2030 from gas power.

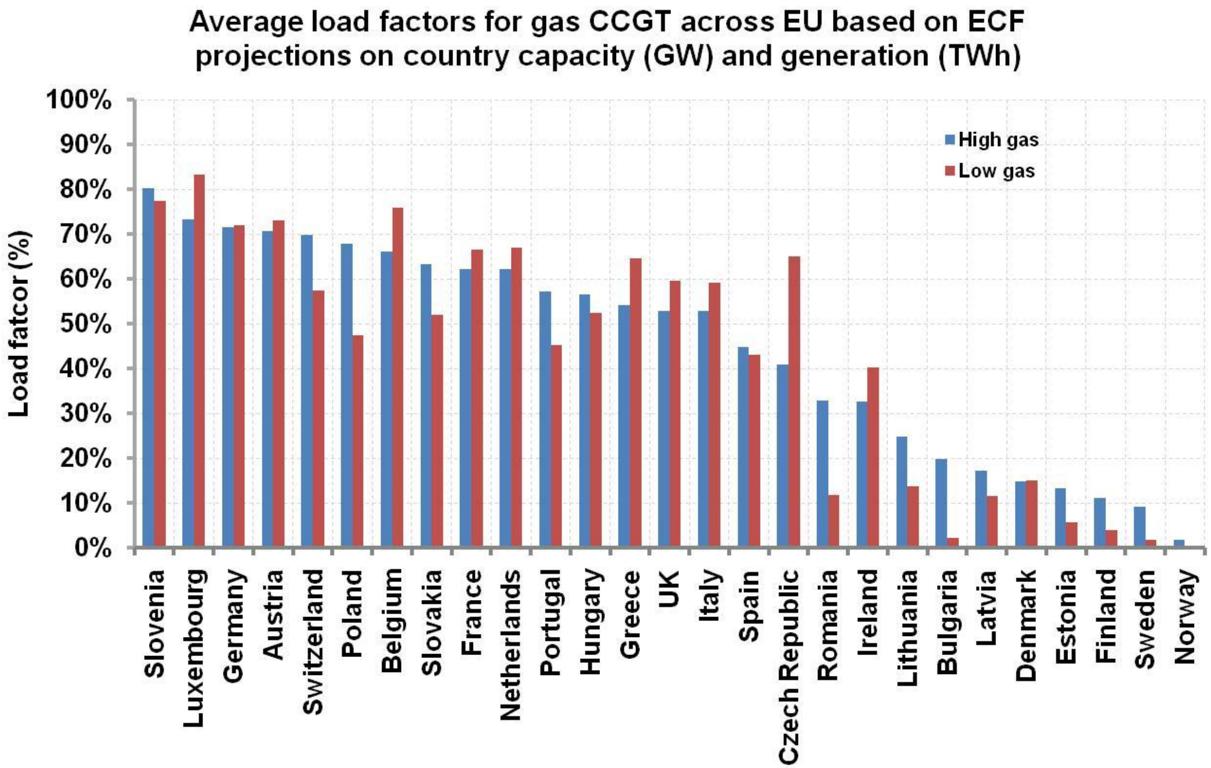


Chosen scenarios:
S13 – Low gas = energy efficiency
S18 – High gas = older plant as backup.

Above scenarios are based on the report *"ECF Power Perspectives 2030"*
http://www.roadmap2050.eu/attachments/files/PowerPerspectives2030_FullReport.pdf

Average load factors are used as an input to determine CO_2 storage requirements

Load factors are determined from ECF scenarios.



In order to calculate the level of CO_2 storage required for each plant, we assume a 20 year project lifetime at the average load factor. Storage demands could be higher if longer projects are assumed or shorter if there is increased competition from other low carbon electricity generation.

Scenarios are developed to assess the impact of different approaches to CCS deployment

- Scenarios that explore different approaches to CCS deployment across the EU27+2 are developed to enable exploration of the potential practical barriers to CCS on gas.
- These scenarios reflect different approaches to:
  - require a more meaningful and proactive approach to capture readiness;
  - develop bankable CO2 storage capacity;
  - enable the transport of CO2 (e.g. via integrated networks shared with coal and industry CCS locations, or via cross-border infrastructure)..
- With all these constraints around capture, storage and transport defined, the model:
  - Calculates the stock in 2030 for each of the high and low gas demand scenarios
  - Determines the sites that are likely to have undertaken meaningful assessments of capture readiness
  - Allocates a storage basin to each capture ready site
  - For capture ready sites, calculates a score for the feasibility of CO2 transport and storage (low, medium and high).
  - Sites which have passed the capture readiness assessment and achieve high scores for transport and storage feasibility are classified as having a practical potential for deployment of CCS in 2030.
- Note: This assessment does not predict whether CCS would be in operation or whether sites would be 'capture ready' awaiting retrofit. Such decisions will depend upon the business case for CCS in the period in advance of 2030.

Defining scenarios for modelling CCS readiness

2030 Gas power stock
- CCGT stock projection (GW)

Capture readiness
- Policy implementation year (early / middle / late adopters)
- Minimum CCS size threshold (MW)
- Repowering frequency (years)

Source-sink allocation
- Theoretical storage available (%)
- Capacity reserved for industry or coal
- Allowance of onshore / cross border
- Storage redundancy needed
- Storage allocation based on score or distance

Transport
- Sharing infrastructure with coal / industrial CCS

Sequence in which the model applies variables to determine overall readiness.

Different variables limit uptake under different scenarios / sensitivities.

Attributes relating to stock, capture readiness, and storage and transport feasibility differentiate the scenarios

Scenario inputs			High Gas			Low Gas		
			Go Slow	Pragmatic	Push	Go Slow	Pragmatic	Push
Stock	Gas CCGT stock projection		S18	S18	S18	S13	S13	S13
Capture readiness	Year of meaningful readiness assessment	Early adopter	2016	2009	2009	2016	2009	2009
		Middle adopter	2016	2012	2012	2016	2012	2012
		Late adopter	2016	2016	2012	2016	2016	2012
	Minimum CCS size (MW)		300	300	300	300	300	300
	Repowering frequency (years)		20	20	20	20	20	20
CO_2 Storage feasibility	Bankable theoretical storage (%)		1%	10%	25%	1%	10%	25%
	Reserved storage for coal and industry		No	Yes	Yes	No	Yes	Yes
	Onshore storage allowed		No	Some countries	All countries	No	Some countries	All countries
	Cross border storage allowed		No	Yes	Yes	No	Yes	Yes
	Storage redundancy required		100%	0%	0%	100%	0%	0%
	Basin allocation based on		Distance	Basin score	Basin score	Distance	Basin score	Basin score
CO_2 Transport feasibility	Network availability		No	No	Yes	No	No	Yes
	Cross border transport allowed		Variable assumed to match changes to whether cross border storage is allowed					

Distribution in 2030 of CCGT stock under "High gas – Go slow" scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

Medium feasibility

Practical potential for CCS

(Stock which is not capture ready omitted for clarity)

Distribution in 2030 of CCGT stock under "Low gas – Go slow" scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

Medium feasibility

Practical potential for CCS

(Stock which is not capture ready omitted for clarity)

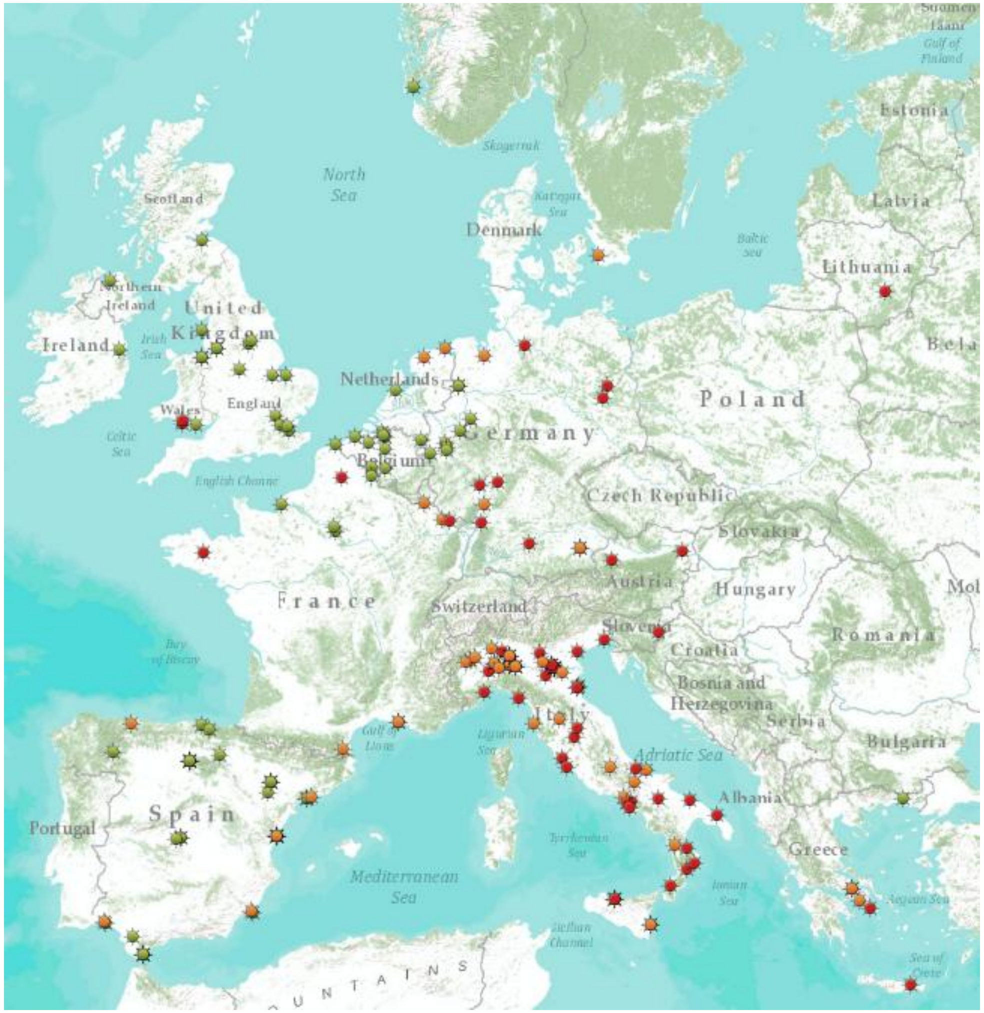
Distribution in 2030 of CCGT stock under “High gas – Pragmatic” scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

Medium feasibility

Practical potential for CCS

(Stock which is not capture ready omitted for clarity)



Distribution in 2030 of CCGT stock under “Low gas – Pragmatic” scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

Medium feasibility

Practical potential for CCS

(Stock which is not capture ready omitted for clarity)

Distribution in 2030 of CCGT stock under “High gas – Push” scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

Medium feasibility

Practical potential for CCS

(Stock which is not capture ready omitted for clarity)

Distribution in 2030 of CCGT stock under “Low gas – Push” scenario according to scores for high, medium and low feasibility for CO2 transport and storage

Low feasibility

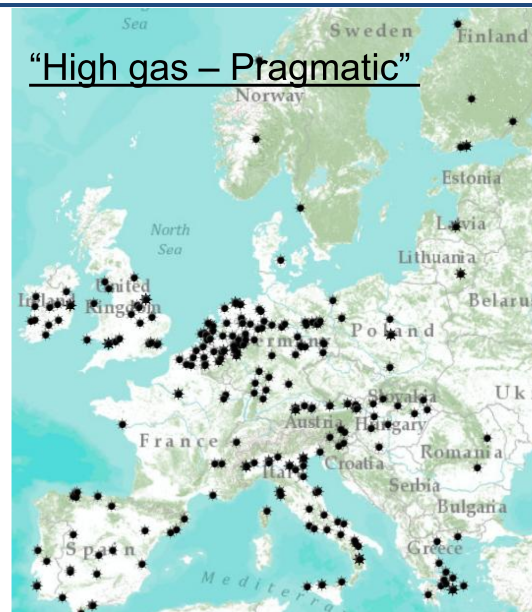
Medium feasibility

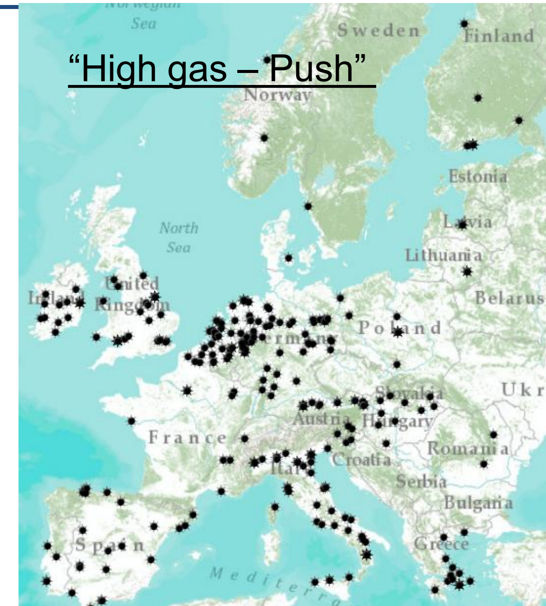
High feasibility
= realistic
potential

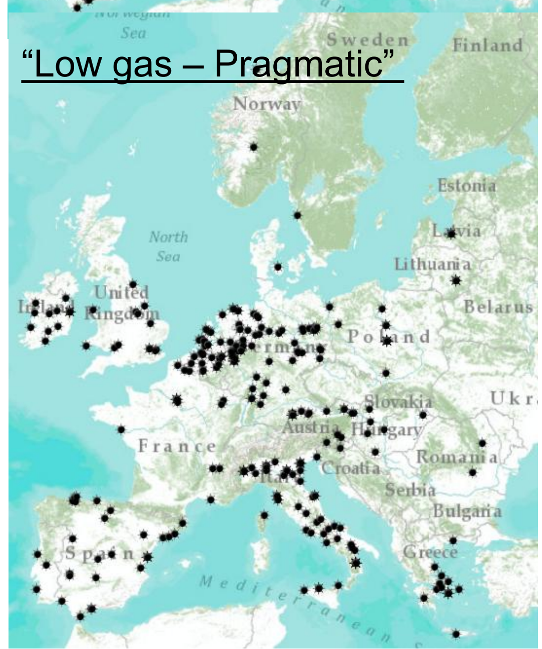
elementenergy

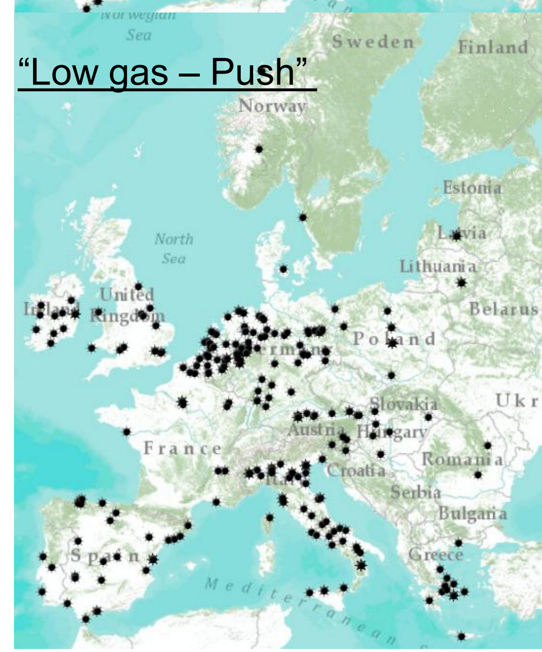
green alliance...

Distribution of CCGT fleet that is modelled as not capture ready by 2030.









Appendix – Contents List

Assumptions for capture readiness assessments

- The modelling assumes that it is only economic to have a site made capture ready if it is either a new build or a currently operational site that is being repowered

- Sites currently under operation are assumed to be repowered every 20 years

- The minimum threshold for making power plant capture ready is 300 MW, based on the CCS Directive

- The year of implementation, i.e. when countries require that new build / repowered gas plants have to undertake meaningful capture readiness assessments (and subsequently proactively ensure appropriate plant configuration), is defined separately for early, middle and late adopters of CCS policy

Results of review of CCS support in Europe

EU country list	Transposition of EC Directive	National legislation on CCS	Evidence of national Govt support	Other political support	Public support for CCS	Industry CCS Demo proposals	History of low carbon energy technology investment and/or ambitious CO2 targets	Evidence of any political or public hostility to CCS	Financial support	OVERALL
Austria	Average	No CCS Support	No CCS Support	No CCS Support	No CCS Support	No CCS Support	Pro-CCS	Average	No CCS Support	No CCS Support
Belgium	Pro-CCS	Pro-CCS	Average		No CCS Support	Average		Average	No CCS Support	Average
Bulgaria	No CCS Support	Average	No CCS Support	No CCS Support		Average		Average	No CCS Support	No CCS Support
Cyprus	Average		No CCS Support					Average	No CCS Support	No CCS Support
Czech Republic	Average	Average	No CCS Support			Average		Average	No CCS Support	No CCS Support
Denmark	Pro-CCS	Average	Average	No CCS Support	No CCS Support	Pro-CCS	Pro-CCS	No CCS Support	Average	Average
Estonia	No CCS Support	Average							No CCS Support	No CCS Support
Finland	Pro-CCS	Average	Average		No CCS Support	Pro-CCS			Average	Average
France	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS	Average	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS
Germany	Average	Average	Average	Average	No CCS Support	Average	Pro-CCS	Pro-CCS	Average	Average
Greece	No CCS Support	No CCS Support	No CCS Support	Average	No CCS Support	No CCS Support	No CCS Support	No CCS Support	No CCS Support	No CCS Support
Hungary	Average	Pro-CCS	No CCS Support	Average	No CCS Support	No CCS Support		Average	No CCS Support	No CCS Support
Ireland	Pro-CCS	Pro-CCS	Average	Pro-CCS	No CCS Support	Average		Average	No CCS Support	Average
Italy	Pro-CCS	No CCS Support	Pro-CCS	Average	Average	Pro-CCS		Average	Average	Pro-CCS
Latvia	Pro-CCS	Pro-CCS	No CCS Support	No CCS Support	No CCS Support	No CCS Support		Average	No CCS Support	No CCS Support
Lithuania	Pro-CCS	Pro-CCS	Average			Average		Average	No CCS Support	Average
Luxemburg	Pro-CCS	Pro-CCS	No CCS Support	No CCS Support	No CCS Support	No CCS Support		Average	No CCS Support	No CCS Support
Malta	No CCS Support	No CCS Support	No CCS Support	No CCS Support	No CCS Support	Pro-CCS		Average	No CCS Support	No CCS Support
Netherlands	Average	Pro-CCS	Pro-CCS	Pro-CCS	Average	Pro-CCS	Pro-CCS	Pro-CCS	Average	Pro-CCS
Norway	Average	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS	Average	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS
Poland	Pro-CCS	Average	Average	Pro-CCS	No CCS Support	Pro-CCS	Average		Average	Pro-CCS
Portugal	Average	Pro-CCS	Average	Average	No CCS Support	No CCS Support	Pro-CCS	Pro-CCS		Average
Romania	Pro-CCS	Average	Pro-CCS	Average		Pro-CCS	Average	Pro-CCS	No CCS Support	Average
Slovakia	No CCS Support	Average	No CCS Support	Average	No CCS Support	No CCS Support		Average	No CCS Support	No CCS Support
Slovenia	No CCS Support	No CCS Support	No CCS Support	Average	No CCS Support	No CCS Support		Average	No CCS Support	No CCS Support
Spain	Pro-CCS	Average	Pro-CCS		No CCS Support	Pro-CCS		Average	Average	Pro-CCS
Sweden	Pro-CCS	Average	No CCS Support	Average	No CCS Support	Pro-CCS		Average	No CCS Support	Average
Switzerland	No CCS Support	No CCS Support	Average	Average	No CCS Support	No CCS Support		Average	Average	No CCS Support
UK	Pro-CCS	Pro-CCS	Pro-CCS	Pro-CCS	Average	Pro-CCS	Pro-CCS	Average	Pro-CCS	Pro-CCS

Pro-CCS

Average

No CCS Support

Inconclusive assessment

A country level socio / political / legislative score is developed to determine early / middle / late adopters of CCS

- Implementation of CCS readiness requires considerable skill and technical capacity. Different member states have different abilities (and enthusiasm) to enforce even light CCS readiness.
- An extensive literature review has been undertaken to assess the attitude of countries in EU27+2 towards adopting CCS in gas CCGT
- This is translated into a score whereby each country is classified as an early, middle or late adopter of meaningful CCS readiness.

Early	Middle	Late
France	Belgium	Austria
Netherlands	Denmark	Bulgaria
Norway	Finland	Cyprus
UK	Germany	Czech Republic
	Ireland	Estonia
	Italy	Greece
	Lithuania	Hungary
	Poland	Latvia
	Portugal	Luxembourg
	Romania	Malta
	Spain	Slovakia
	Sweden	Slovenia
		Switzerland

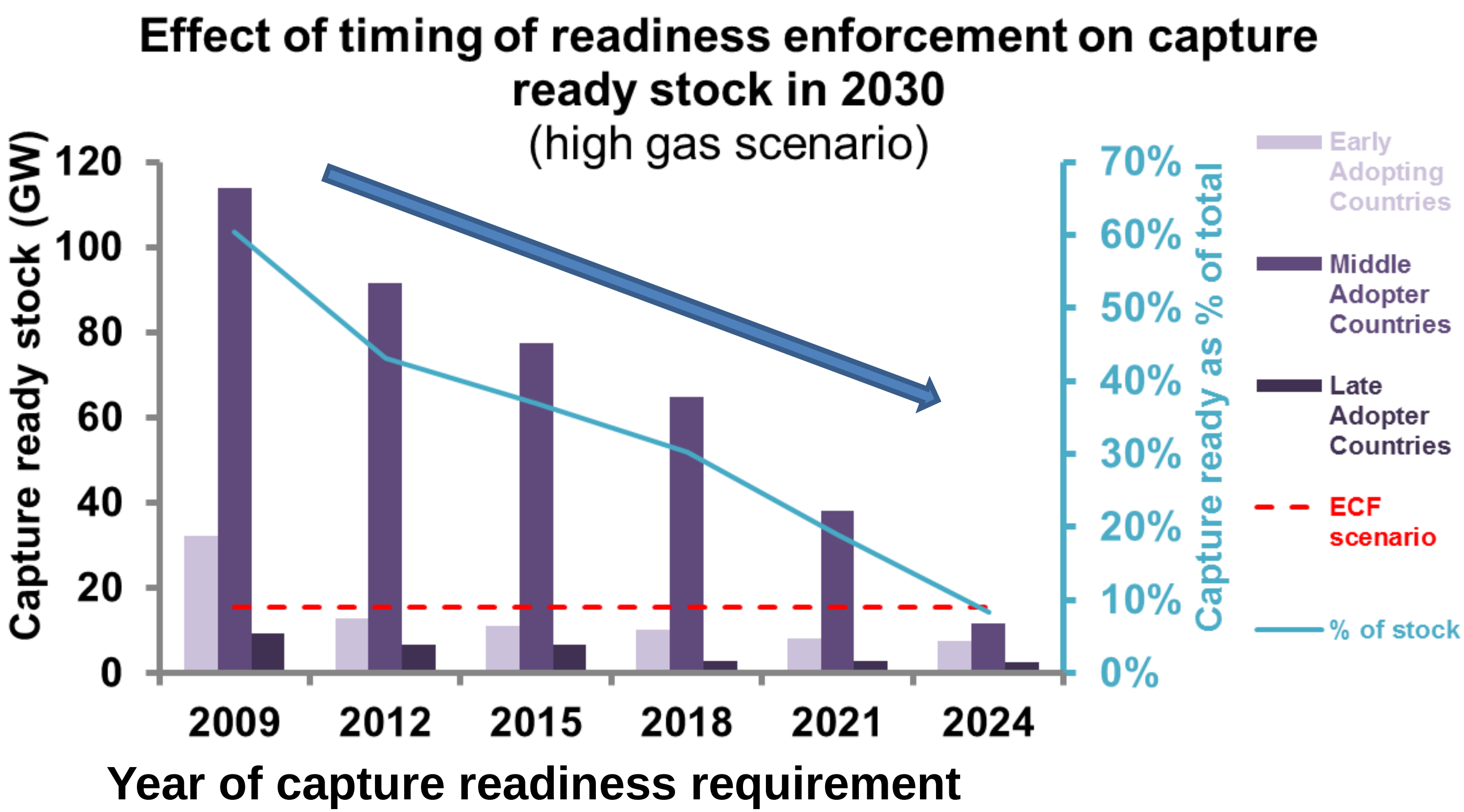
The dates at which capture readiness requirements are implemented for new and repowered gas plants defines the capture ready stock

Scenario	Early Adopters	Middle Adopters	Late Adopters
Go Slow	2016	2016	2016
Pragmatic	2009	2012	2016
Push	2009	2012	2012

- The Platts database provides an estimate of commissioning date.
- Following regulatory approval for a new gas power investment, there will be a final investment decision (FID), procurement process, and construction period before the plant is commissioned.
- Therefore we assume a 5 year delay between regulatory approval and plant operation, i.e. under the Pragmatic scenario, capture ready plants in early, middle and late adopter countries would be operational in 2014, 2017 and 2021 respectively.

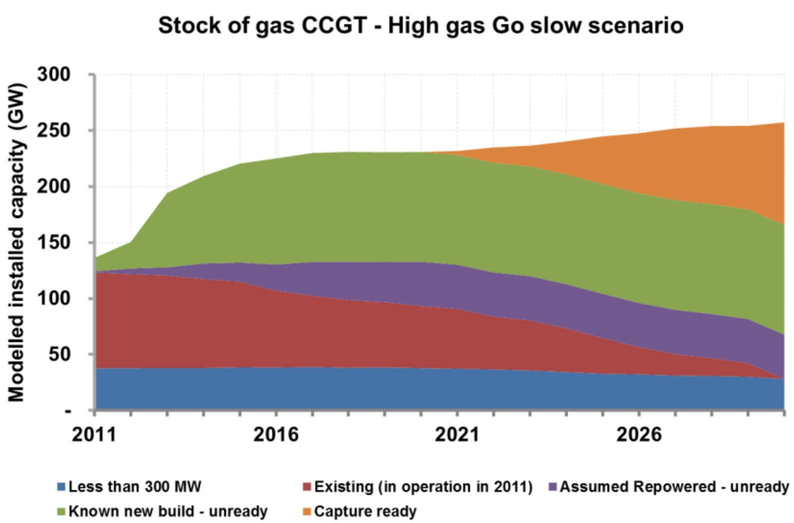
The timing of imposition of capture readiness has a strong influence on the capture ready stock in 2030.

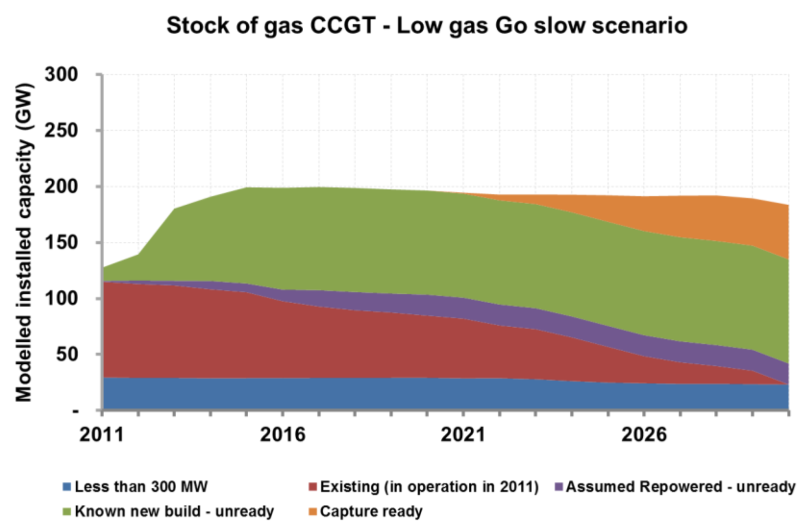
- The ECF scenarios of up to 16GW CCGT CCS in 2030 correspond to 5-10% of stock.
- Delays in implementing requirements for capture readiness in middle adopter countries significantly reduces the capture ready stock for 2030 and beyond
- Germany, Italy and Spain are all in this category of countries, and each has significant predicted gas capacity to 2030



The stock of gas CCGTs for the Go slow scenario shows a delayed uptake of capture ready plant for both High and Low gas demand

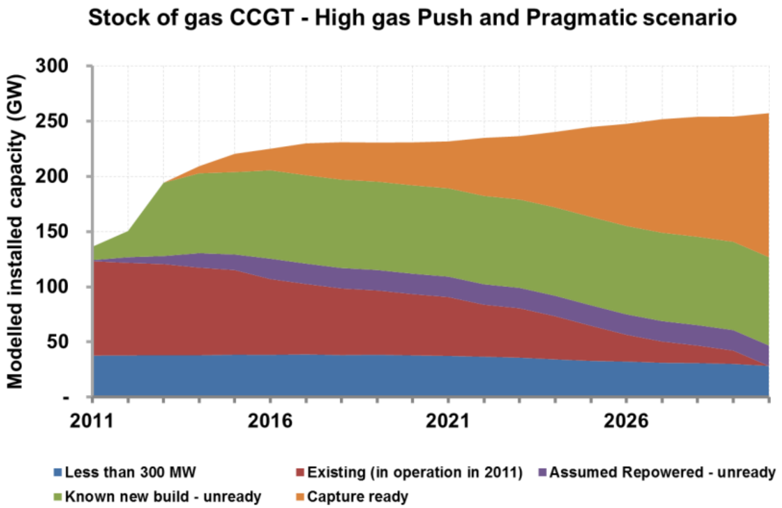
- Under the Go Slow scenario, capture readiness assessment is required for plants consented from 2016 onwards. The first capture ready plants only appear from 2021 onwards, due to a 5 year delay from policy to site commissioning
- This delay causes a lost opportunity for new builds to be made capture ready in the period to 2020.

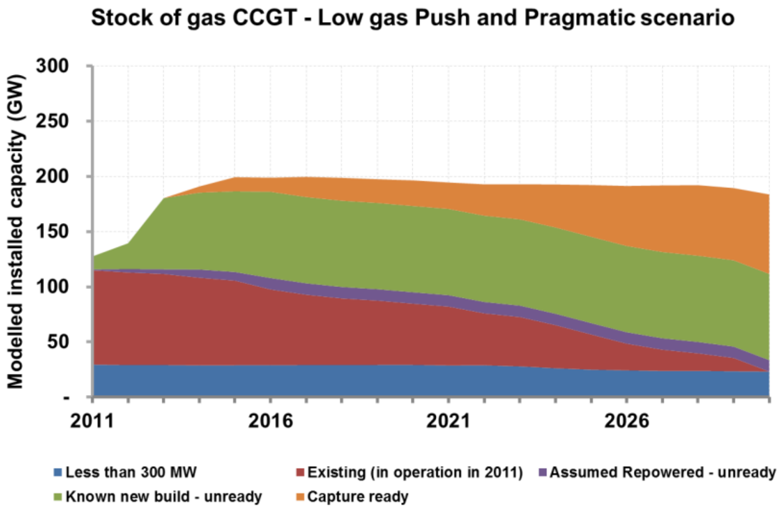




A larger proportion of the gas CCGT stock is capture ready for Pragmatic and Push scenarios for both High and Low gas demand

- For both early and middle adopters, under the Pragmatic and Push scenarios capture readiness assessment is required from 2009 and 2012 respectively.
- New builds and repowered sites therefore start operations as capture ready plant from 2014 and 2017 onwards, due to a 5 year delay from policy to site commissioning.
- This results in a larger proportion of the stock in 2030 operating under capture readiness conditions (or indeed coming forward as new build gas plant with CCS integrated from the outset).
- Late adopters face an earlier date for capture readiness assessments under the Push scenario (2012) compared to the Pragmatic scenario (2016). This however has no impact on the overall capture ready stock, since there is no new build or repowered site predicted for these late adopter countries in those timeframes.





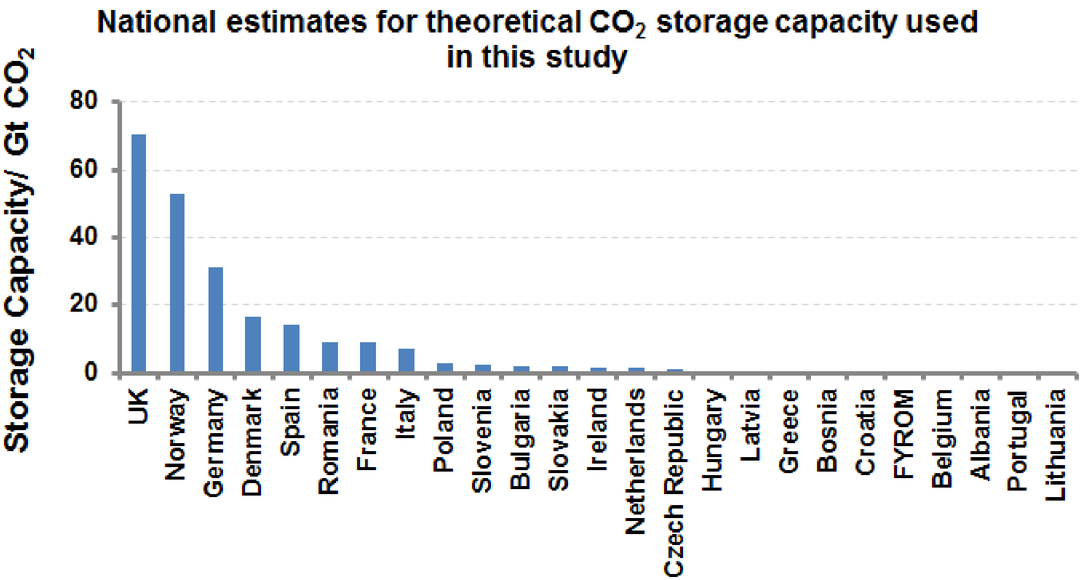
Appendix – Contents List

The development of bankable storage across Europe is required to enable widespread realistic potential for CCS

- CO_2 storage can take place in depleted hydrocarbon fields, which are well characterised, as well as saline aquifers which will need significant investment for appraisal.
- A capture ready site requires access to CO_2 storage capacity and CO_2 transport options in order for it to ensure its practical potential to operate with CCS.
- Individual CCGTs will require access to CO_2 storage equivalent to the emissions from the plant over its lifetime, taken as 20 years.
- To calculate the access to storage, a detailed database is developed based on estimates of the theoretical storage capacity for each country.
- Capture ready sites are allocated to these storage basins based on their location and their bankable capacity.
- This allocation could be constrained by access to onshore or cross border storage and whether CO_2 storage is reserved for industry and coal CCS projects.
- As a further but plausible restriction we consider the need for an individual CCGT to have redundancy of storage capacity within a basin as a risk mitigation strategy.
- The user may also define a minimum redundancy requirements (unreserved/reserved bankable storage) to reduce storage risk, whereby the sinks are not filled above a certain share of bankable storage.
- Thus a basin is only available if it meets location constraints and if there is enough unreserved capacity available in the bankable storage, after lifetime emissions have been reserved, to meet redundancy criterion.
- In the “Go Slow” scenarios, the default redundancy requirement is set at 100%, i.e. twice as much storage capacity is required. This restriction is removed for the pragmatic and push scenarios.

Published literature is used to create a basin-level storage database across Europe

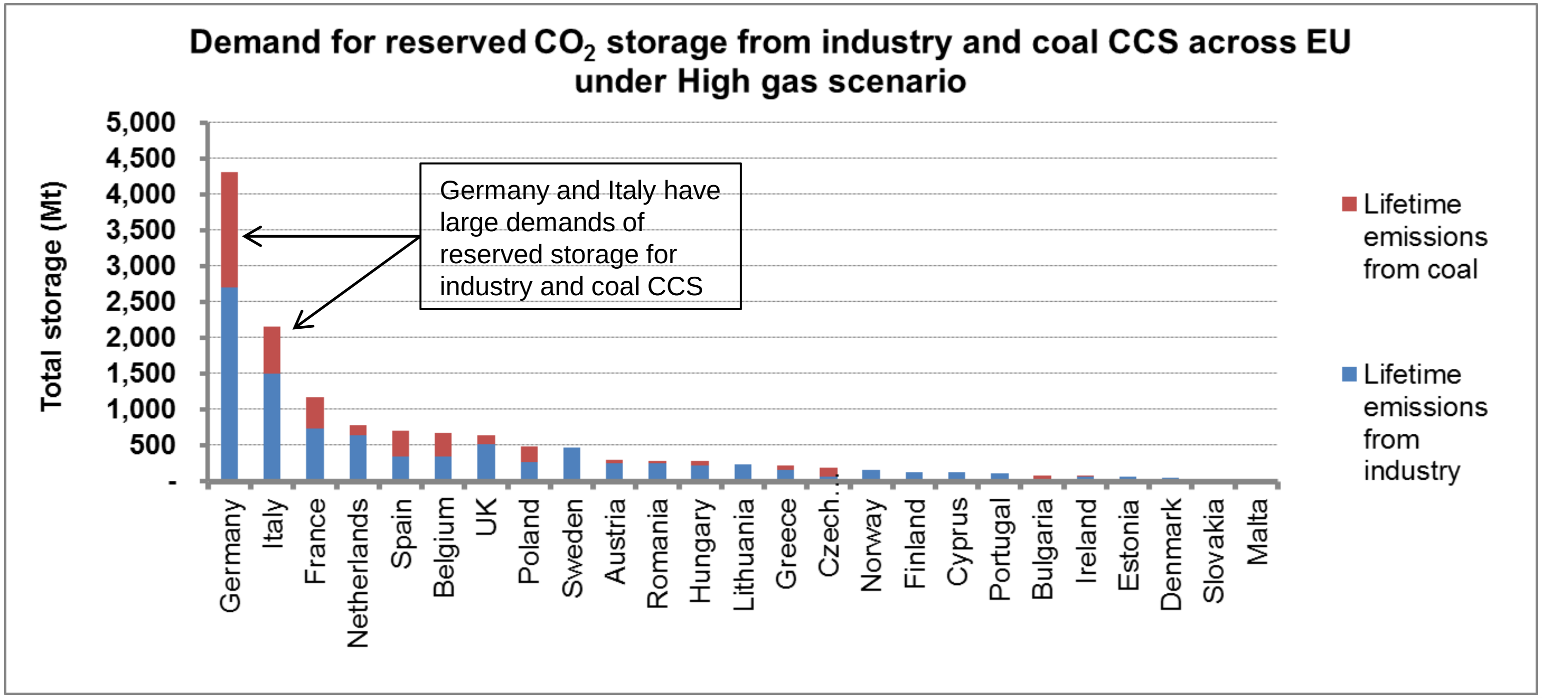
The model has a database of 56 storage basins in 25 countries with a cumulative capacity of 226 Gt, consisting of 47 aquifers (208 Gt) and 9 hydrocarbon (18 Gt).



Aggregated national estimates for theoretical capacity and approximate basin locations were collated from the GeoCapacity, SCCS/Arup, and NSBTF studies. Basins were converted to quadrilaterals for GIS. Please consult these sources for references to the primary academic literature. Note that different geological settings imply a need for different methodologies for estimating CO_2 storage capacity, and a wide range of procedures (some inconsistent) have been reported to derive these theoretical capacities. [Details available on request]

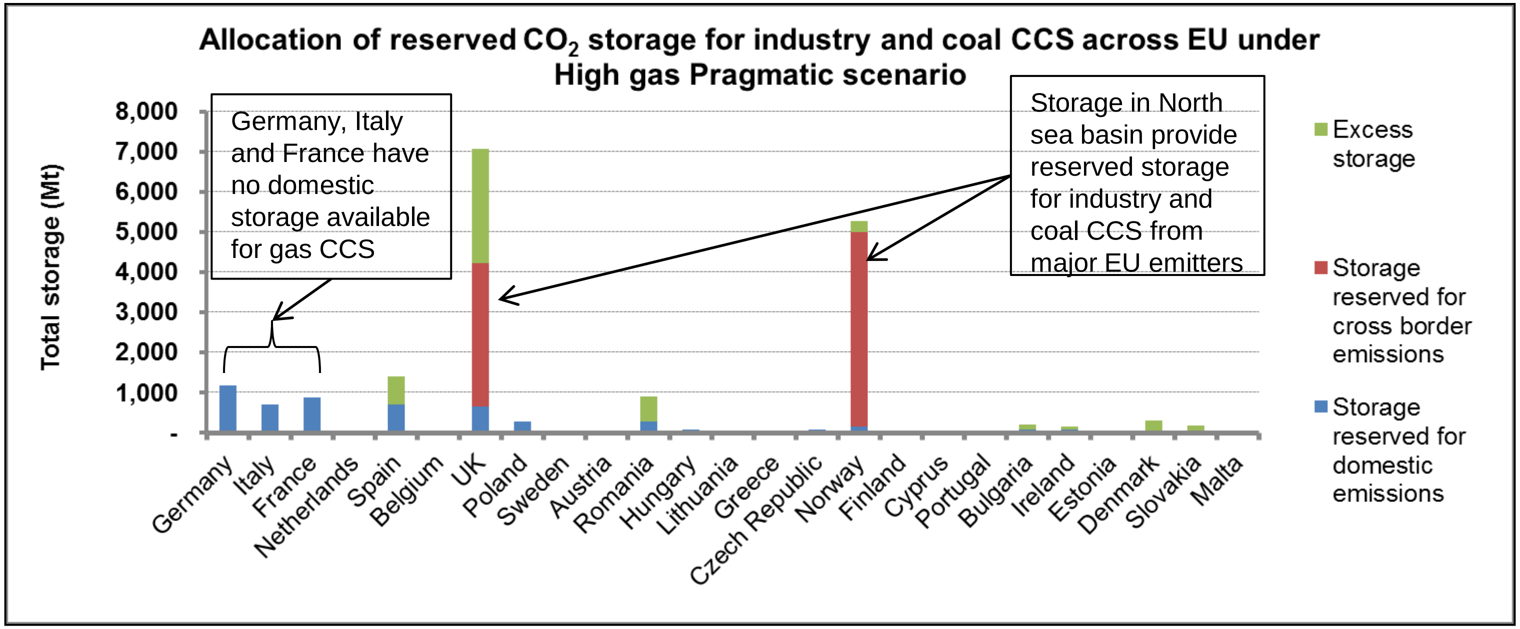
IEA GHG database of EU industrial emissions and ECF coal CCS projections are used to identify competition for storage and potential for connection to a shared CO_2 transport network.

- The IEA GHG sources database provides a list of stationary sources that was filtered to obtain sources with annual emissions >1MtCO_2 and located in EU27+2.
- These emissions, along with those based on coal CCS projected in the ECF scenario, are used, subject to scenario constraint, to reduce the available storage capacity for capture ready gas CCGT.
- Germany and Italy show large demands of reserved storage from industry and coal CCS and thus need significant domestic storage or access to cross border storage.



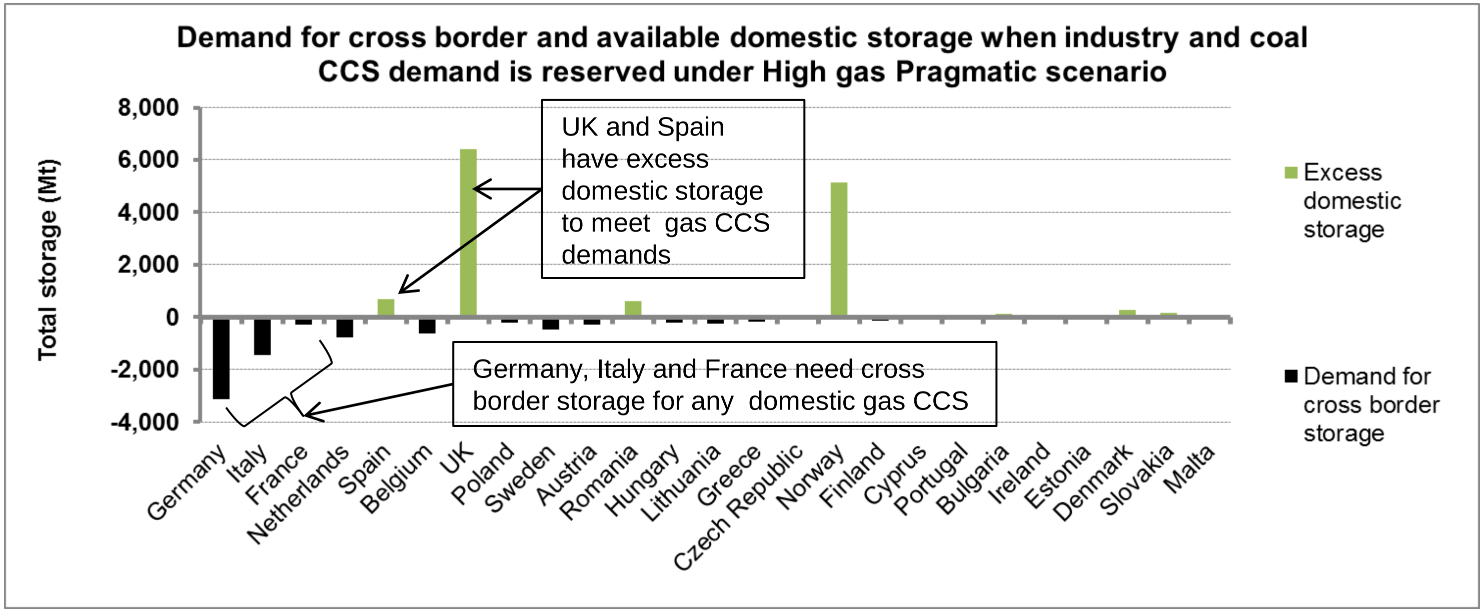
The demands of reserved storage from industry and coal CCS is met from domestic sinks and neighbouring countries if domestic storage is insufficient

- Storage for industrial and coal CCS emissions is initially reserved in domestic basins before cross-border transport and storage of CO_2 to neighbouring countries is considered.
- Countries with low bankable storage or high demands of reserved storage need access to cross border storage for further uptake of gas CCS
- Under High gas Pragmatic scenario; Italy, France and Germany are totally reliant on cross border storage, since they have no excess domestic storage available after demands from industry and coal CCS are reserved



With demands from industry and coal CCS reserved; Germany, Italy and France rely completely on cross border storage for gas CCS while UK and Spain can meet gas CCS demand from domestic storage

- Due to high domestic demands in Germany, France and Italy, no domestic storage is available for capture ready gas sites if storage is reserved for industry and coal CCS
- They rely on access to cross border storage to meet demands from domestic capture ready gas sites
- UK and Spain still have domestic capacity available and can provide storage for capture ready sites in neighbouring countries

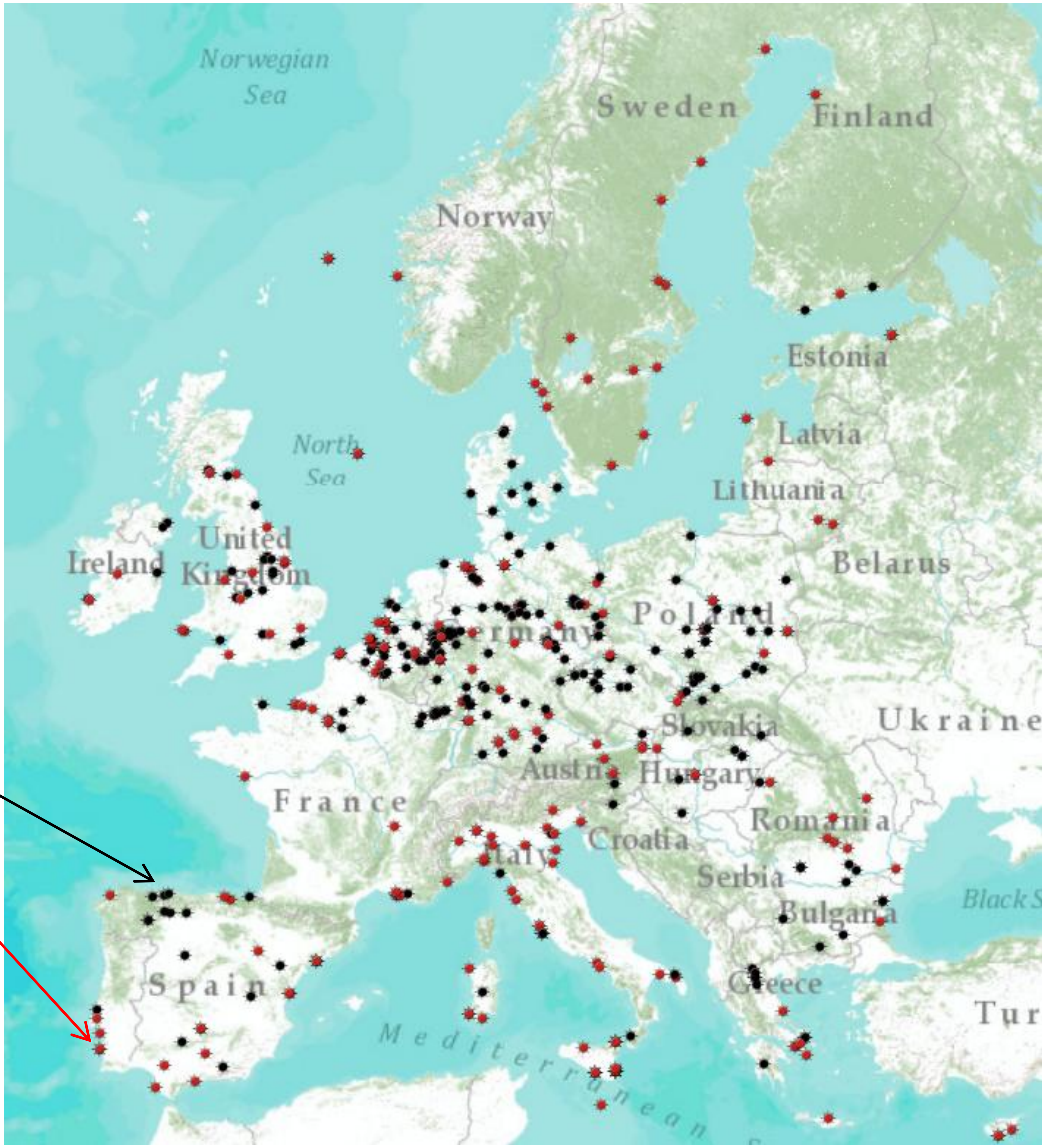


Existing large stationary industrial and coal CO_2 emissions are concentrated in Germany, Italy, France, Netherlands, Spain and UK

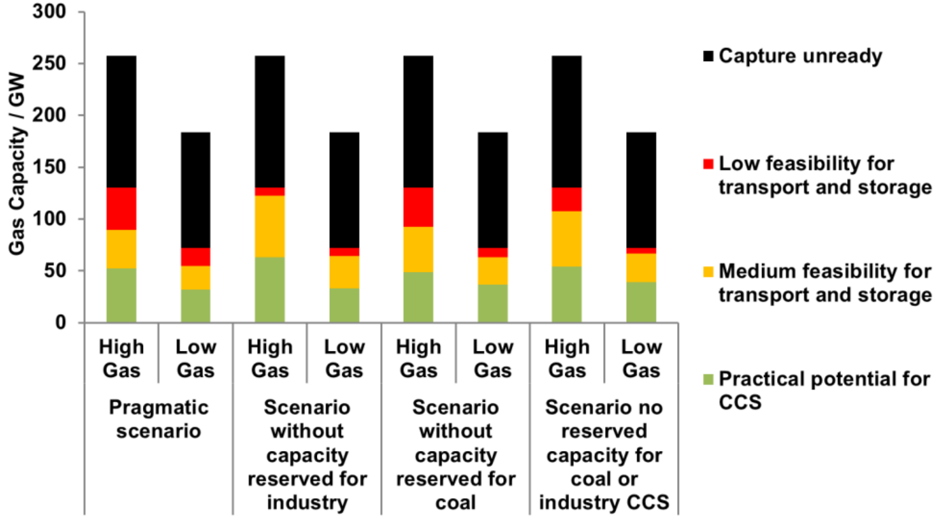
Points show locations of industrial and coal emitters in the IEA GHG database

Coal

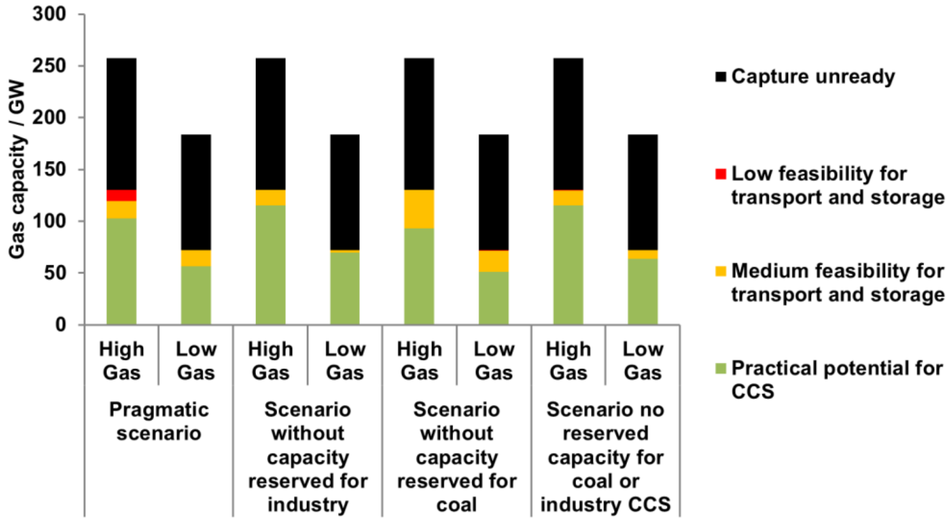
Industry



Impacts of reserving storage for coal or industry CCS



Relative to the Pragmatic scenario, removing Coal CCS or industry CCS frequently results in a switch in the source-sink match, although overall improvements in practical potential are relatively limited.



Relative to the Push scenario, removing Coal CCS or industry CCS improves availability of storage but reduces transport potential. Therefore, although there are potentially large changes in source-sink matches, the overall impact on gas CCS practical potential is limited.

Appendix – Contents List

The source-sink matching allows for weighting of available storage redundancy and/or distance between source and sink.

- Transport issues revolve around pipeline construction from the capture ready site to the storage and involves issues around planning and terrain, especially for pipelines sited onshore

- The availability of a basin is defined by scenario constraints around location (onshore and cross border) and redundancy (meeting minimum unreserved/reserved bankable storage) after site lifetime emissions are reserved

- The model allocates each capture ready site to an available storage basin, with the sites prioritised firstly by year of commissioning (2011-2030) and then by size (MW)

- This allocation methodology, defined by scenario, is based on either:
  - Basin score, i.e. the basin offering the highest storage redundancy for the source, (i.e. the ratio of bankable storage to the reserved capacity). In case of more than one site with the highest score, the nearest site is preferred.
  - Basin distance, i.e. the storage basin with the shortest distance is preferred.

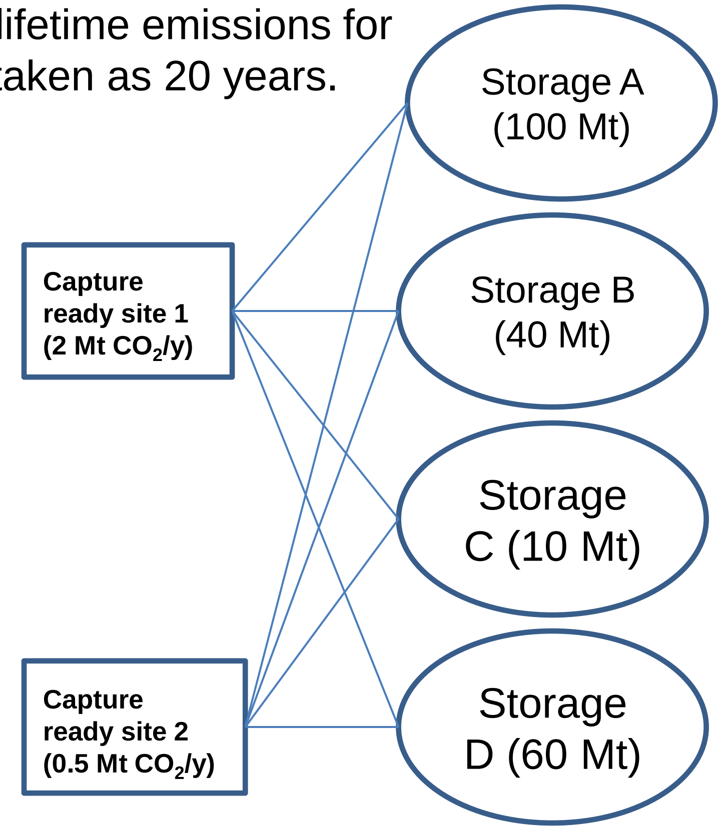
- The bankable storage capacity depends upon the scenario-defined theoretical storage availability (%), while the reserved capacity is the cumulative lifetime emissions of all capture ready sites allocated to the basin to date.
- In the “Go Slow” scenario, the default option is “Basin Distance”, with a minimum storage redundancy of 100%. In the “Pragmatic” and “Push” Scenarios, scoring reflects storage capacity.

Illustrative example of storage allocation (multiple sinks and capture ready sites)

The example shown below considers two capture ready sites that have access to four storage basins. The annual emissions from the capture ready sites and bankable capacity of each basin is shown. The distances to these storage basins as well as the ratio of bankable storage to lifetime emissions is tabulated below. The basin has to be able to provide lifetime emissions for the capture ready site to be considered. The lifetime is taken as 20 years.

Score	Distance	Storage (bankable/reserved)
1	<100 km	>2
0.66	100 - 300 km	2 – 1.25
0.33	>300 km	<1.25

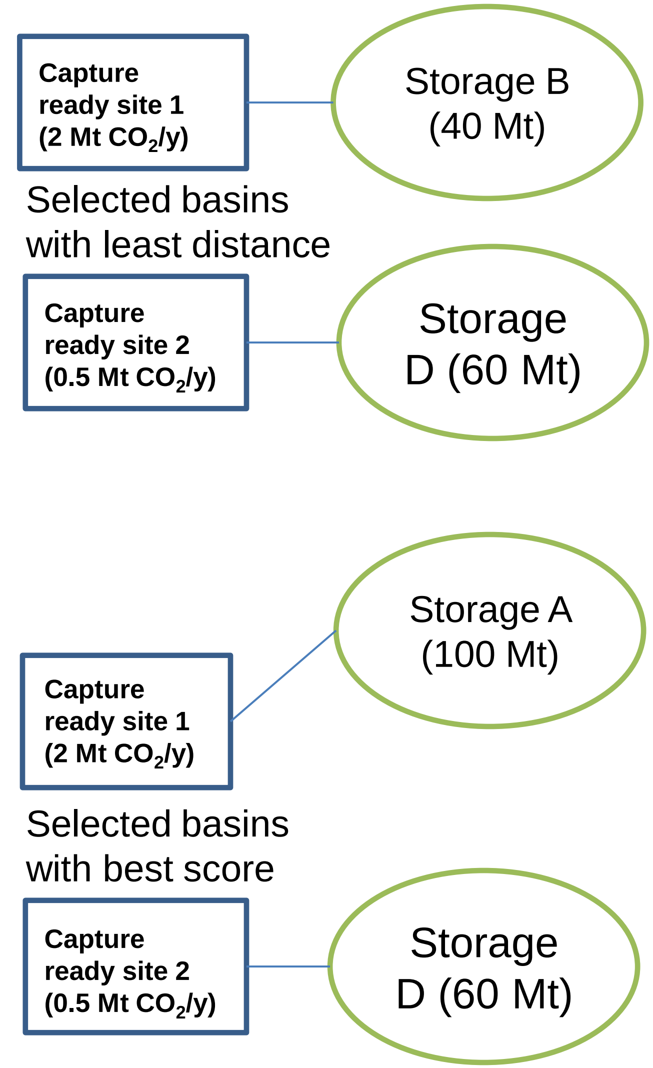
Capture ready sites	Distance to sinks (km)				Bankable/reserved storage ratio			
	A	B	C	D	A	B	C	D
Site 1	160	90	160	310	2.5	1	0.25	1.5
Site 2	320	150	120	80	10	4	1	6



Storage score and allocation to capture ready sites under different selection scenarios

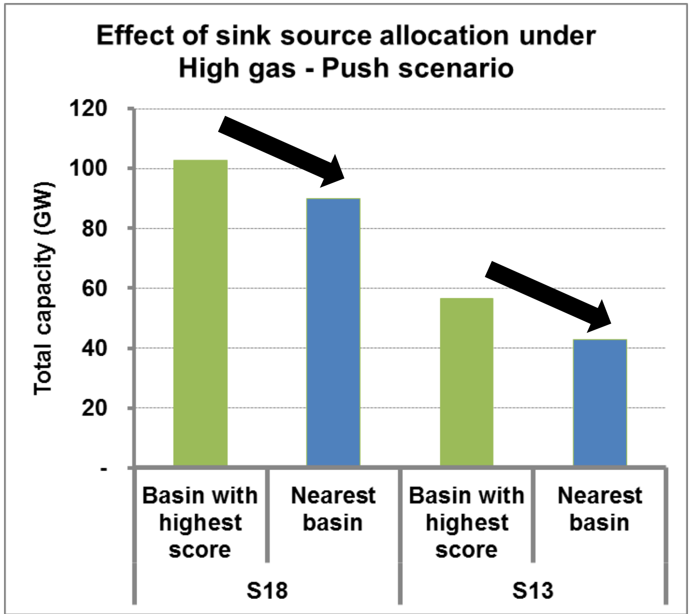
The selection of the basins on the previous slide is shown in the table below for different scenarios. Under the basin selection criterion of distance, the nearest basin with capacity sufficient for lifetime emissions is selected. However with the criterion changed to basin score, basin with the overall best score (based on transport and storage) is selected.

Storage basins		Site 1 Scores			Site 2 Scores		
		Storage	Transport	Final	Storage	Transport	Final
A		1	0.66	0.66	1	0.33	0.33
B		0.33	1	0.33	1	0.66	0.66
C		0.33	0.66	0.22	0.33	0.66	0.22
D		0.66	0.33	0.22	1	1	1
Storage selection scenario	Distance	B			D		
	Basin score	A			D		



A strategic allocation of storage capacity results in higher levels of realistic potential for gas CCS

- Two approaches are examined for how capture ready sites compete for storage.
- With low storage planning, e.g. in the “Go Slow” scenario, it is assumed sources prefer basins with sufficient capacity based on distance.
- Once a site is allocated to a basin, the available capacity of that basin is reduced by the amount of lifetime emissions of the allocated capture ready site.
- However, this can result in inefficient use of the storage.
- Therefore a second approach was developed to maximise the use of storage (e.g. in the “Pragmatic” and “Push” scenarios.
- If capture ready sites are connected to basins with the highest score (based on both distance and the redundancy available), basins are less likely to be filled to capacity.
- This enables higher scores for storage feasibility for a greater number of capture ready sites.



Level of realistic potential for CCS reduces if sites ‘cherry pick’ nearest CO_2 storage basins rather than storage being allocated in a more strategic approach

Appendix – Contents List

The practical potential for CCS is determined based on the scores awarded to capture ready plant in respect to the feasibility for CO_2 storage and transport

For each capture ready site a score of the feasibility of CO_2 storage and transport is calculated, based on three attributes.

- Storage redundancy, expressed as filling ratio of the allocated basin (bankable storage / reserved capacity), where reserved capacity is based on cumulative lifetime emissions from all the capture ready sites connected to the allocated basin. This score improves with higher redundancy to reflect reduced risk around storage development.

Condition	Storage redundancy ratio	Storage score
Greater than	2	High - 1
Else	1.25 - 2	Medium - 0.667
Less than	1.25	Low - 0.333

- The distance to the allocated basin, broken into onshore and offshore components. The score improves for lower distances as well as a higher proportion being offshore, since planning hurdles and other obstacles around routing are higher for onshore pipelines.

Condition	Distance (km)		Transport score
	Onshore	Offshore	
Both less than	100	300	High - 1
Else	100 - 300	300 - 500	Medium - 0.67
Either greater than	300	500	Low - 0.33

- The availability of integrated CO_2 transport networks also improves the transport score. This is based on the proximity of capture ready gas power sites to industrial and coal CO_2 sources. The opportunity here is for gas plant to benefit from transport infrastructure developed for coal or industry.

The practical potential for CCS is determined by calculating scores for CO_2 transport and storage feasibility for capture ready sites

- The final score is based on a product of the individual transport and storage scores. Capture ready sites with a final score greater than 0.66 are classified as having a practical potential for CCS.

Final score	Scoring categorisation
1 - 0.67	Practical potential for CCS
0.66 - 0.34	Medium feasibility for transport and storage
0.33 – 0.01	Low feasibility for transport and storage

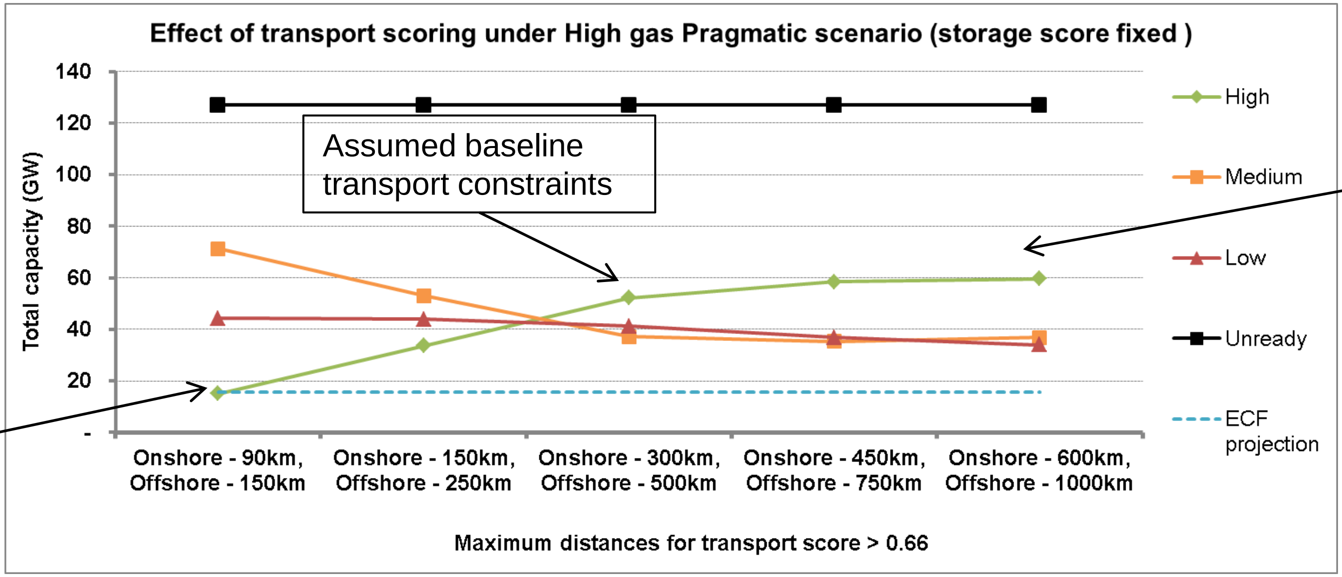
- Thus in order for a site to be classified as having a practical potential for CCS, it needs to have one of the following combinations:
  - High transport and high storage score
  - High transport and medium storage score
  - Medium transport and high storage score

Overall scores for realistic potential for CCS		Transport score		
		High	**Medium**	**Low**
Storage score	**High**	High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Low

Sensitivity analysis of transport scoring methodology for "High gas – Pragmatic scenario"

- The transport score acknowledges risks around the construction of pipelines from capture ready sites to distant basins, as well as the proportion of pipeline needed onshore.
- By varying the constraints around maximum pipeline lengths that avoid high transport risk, the robustness of findings to variations in CO_2 transport assumptions is tested.
- The sensitivity analysis reveals that if pipeline length has to be lower than 90km onshore and 150km offshore to avoid high transport risk, the level of plant achieving a realistic potential for CCS under the "High Gas, Pragmatic" scenario can still meet ECF projections for 2030

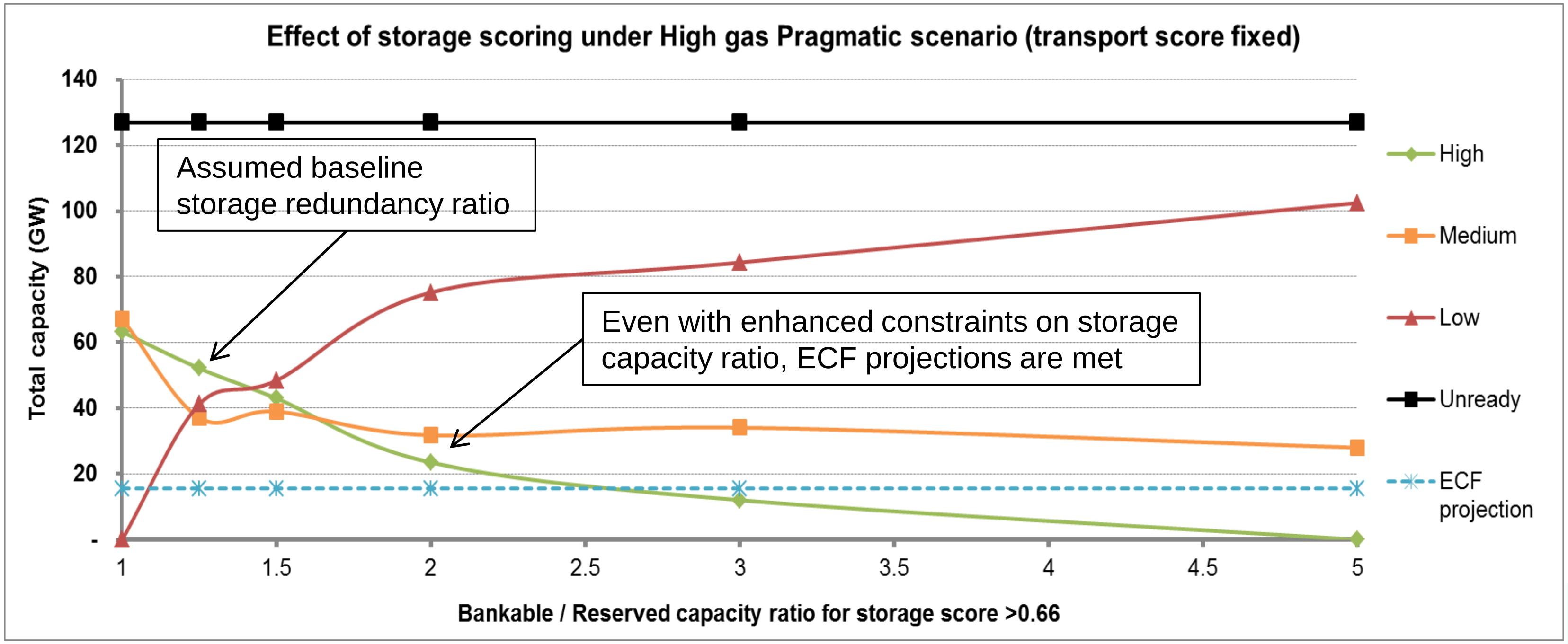
Even with enhanced constraints on onshore and offshore pipelines length, ECF projections are met, but the level of practical potential for CCS is significantly reduced



CCGT stock with practical potential for CCS sees only a slight increase from relaxed transport constraints

Sensitivity analysis of storage scoring methodology for "High gas – Pragmatic scenario"

- The storage score acknowledges risks around the filling of storage basins from allocated capture ready sites and the redundancy available for uncertainties around development.
- By varying the constraints around the minimum bankable / reserved storage ratios needed to avoid high storage risk, the robustness of findings to variations in storage assumptions is tested
- The sensitivity analysis reveals that if a minimum storage redundancy ratio of 2 is needed to avoid high storage risk, the stock with realistic potential for CCS under the "High gas, Pragmatic" scenario can still meet ECF projections.



Appendix – Contents List

1. Model schematic , methodology and assumptions
2. Scenarios
    I. High and Low CCGT capacity in 2030
    II. Degree of CCS development
3. Capture readiness
    I. Methodology
    II. Inputs & Assumptions
    III. Results & Sensitivities
4. Storage
    I. Methodology
    II. Inputs & Assumptions
    III. Results & Sensitivities
5. Transport
    I. Methodology
    II. Inputs & Assumptions
    III. Results & Sensitivities
6. Scoring
    I. Methodology
    II. Inputs & Assumptions
    III. Results & Sensitivities
7. Selected high level country summaries

Highlights of model inputs and outputs for selected countries

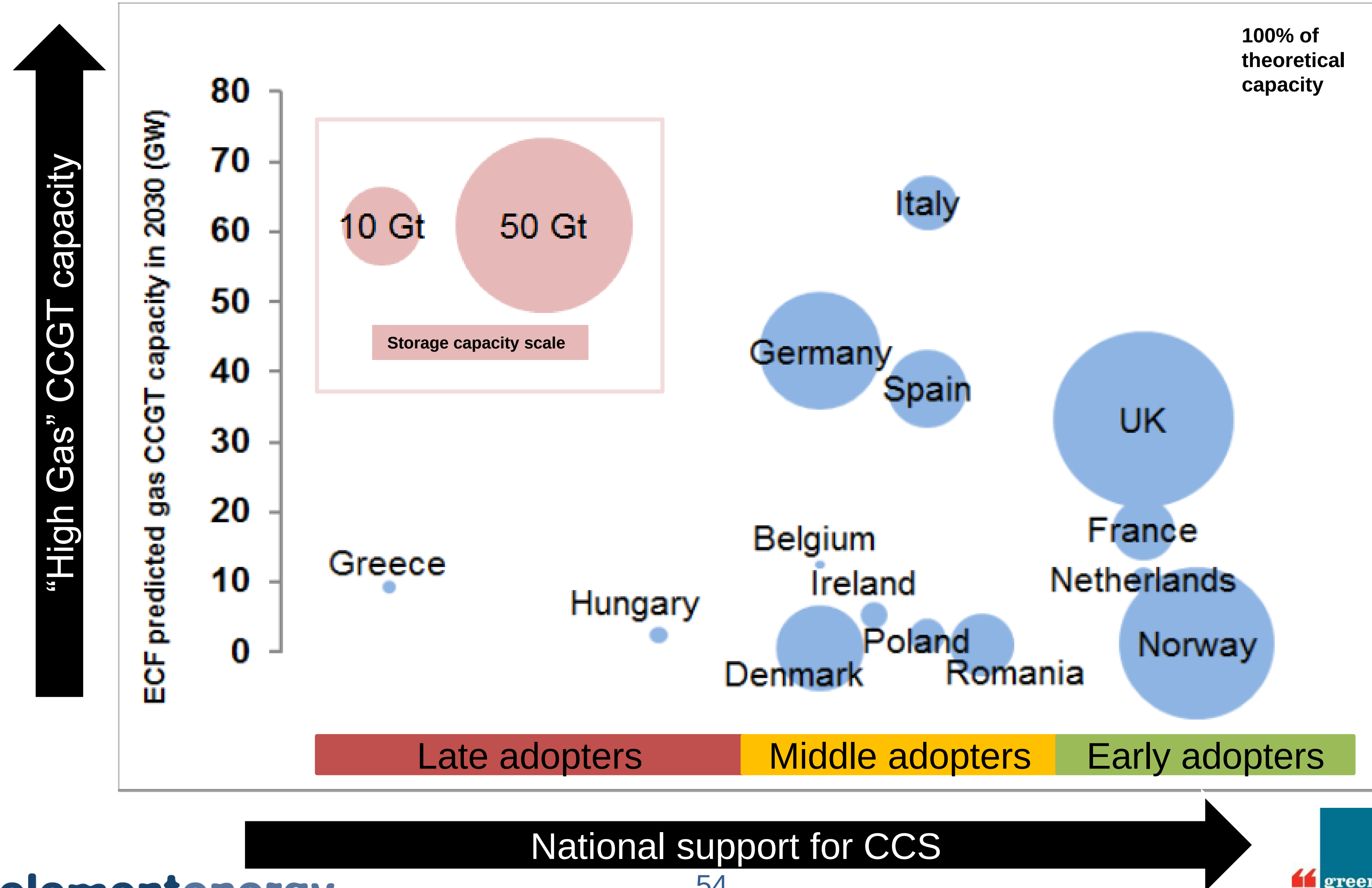
The graphs in the subsequent slides illustrate

- ❑ The distribution of operational and planned CCGTs
- ❑ The predicted CCGT capacity in 2030
- ❑ The modelled distribution of stock over time
- ❑ Modelled storage capacities relating to storage availability restrictions (% bankable, use of onshore)

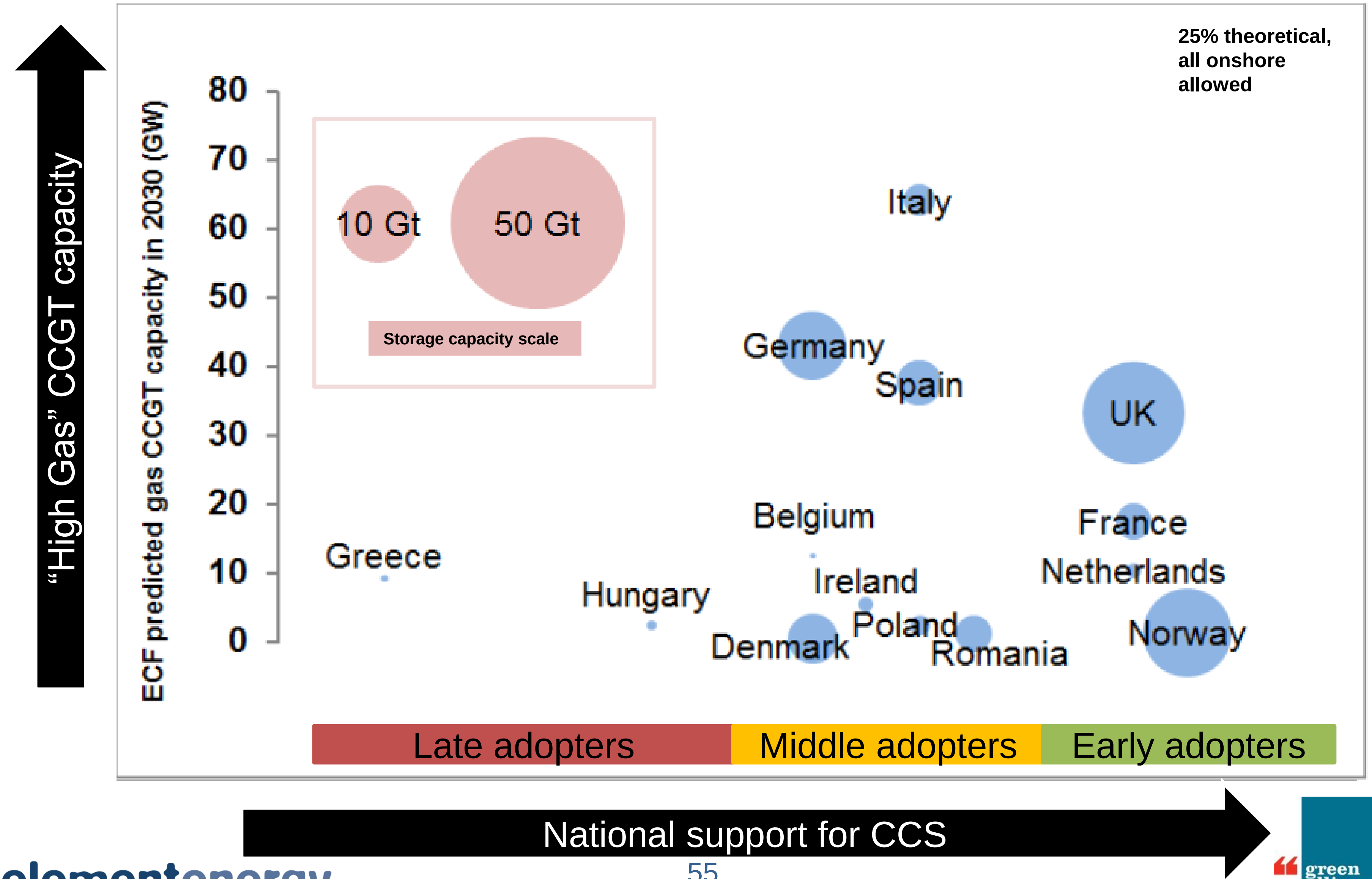
The highlights from the sensitivity analysis are used to provide commentary on country specific issues. Note that as identified previously, multiple issues can raise/lower the practical potential for gas CCS across the fleet. Decisions taken in one country can impact the potential of neighbouring countries.

Note that “over-analysis” of country-level outputs is not warranted, due to multiple limitations across country-level inputs and assumptions.

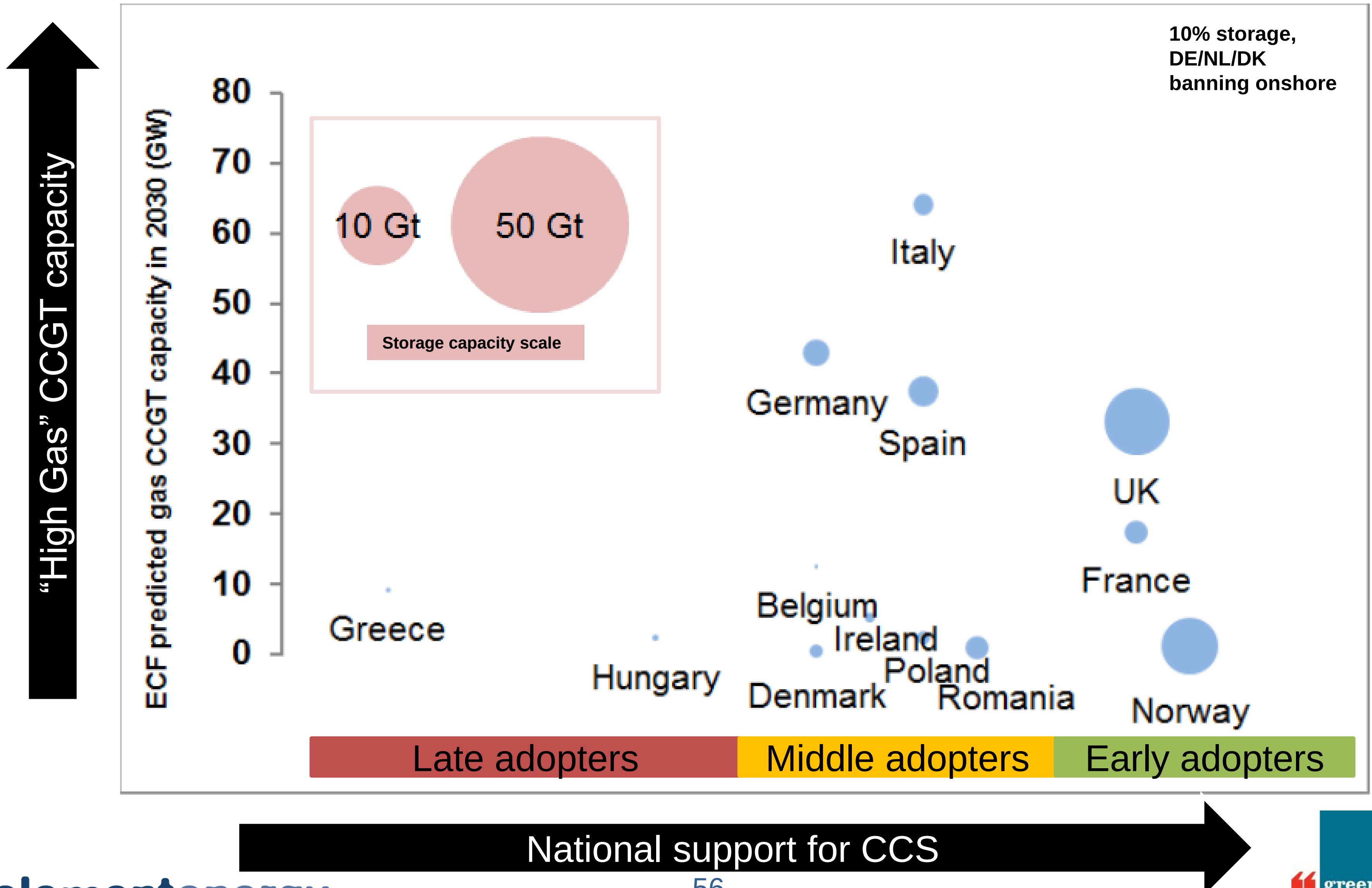
Comparison of domestic storage capacity, assuming 100% theoretical storage availability, with forecast CCGT capacity in the "High Gas" scenario, and current CCS support by country.



Comparison of domestic storage capacity, assuming 25% of theoretical storage availability, with CCGT capacity in the "High Gas" scenario, and current CCS support by country.



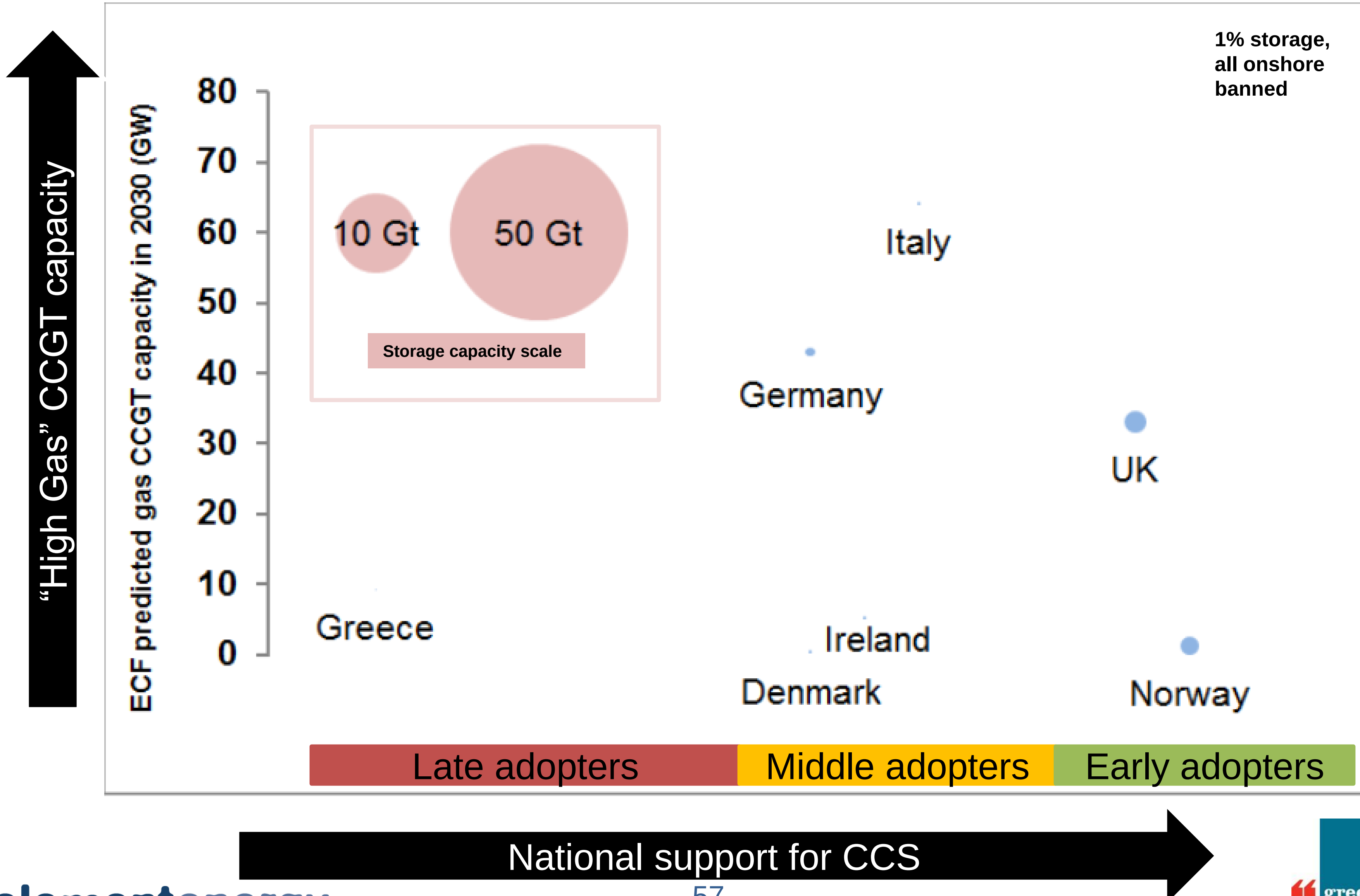
Comparison of domestic storage capacity, assuming availability of 10% of theoretical storage capacity and with onshore storage restricted in DE, NL and DK, with forecast CCGT capacity in the "High Gas" scenario, and current CCS support by country.



element energy

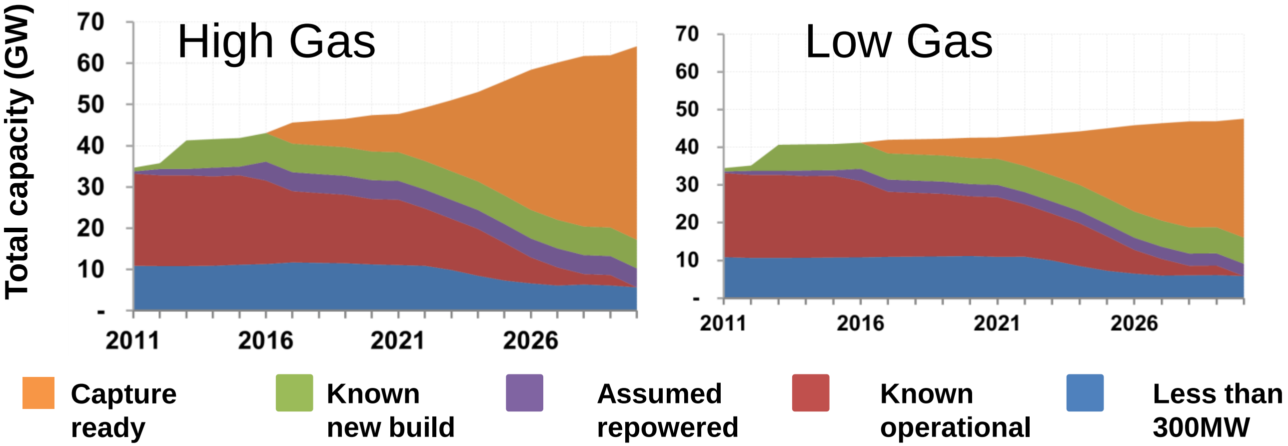
green alliance...

Comparison of domestic storage capacity, assuming 1% of theoretical capacity is available and no onshore storage in any country, with forecast CCGT capacity in the "High Gas" scenario, and current CCS support by country.



Italy

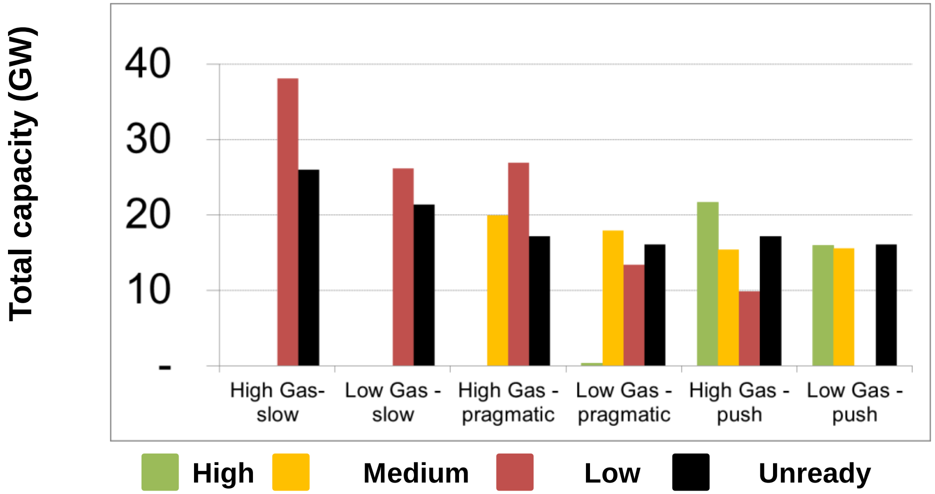
Stock of gas CCGT under Pragmatic scenario



Map shows input CCGT locations:
Operational
Under construction
Planned

7 Gt theoretical storage

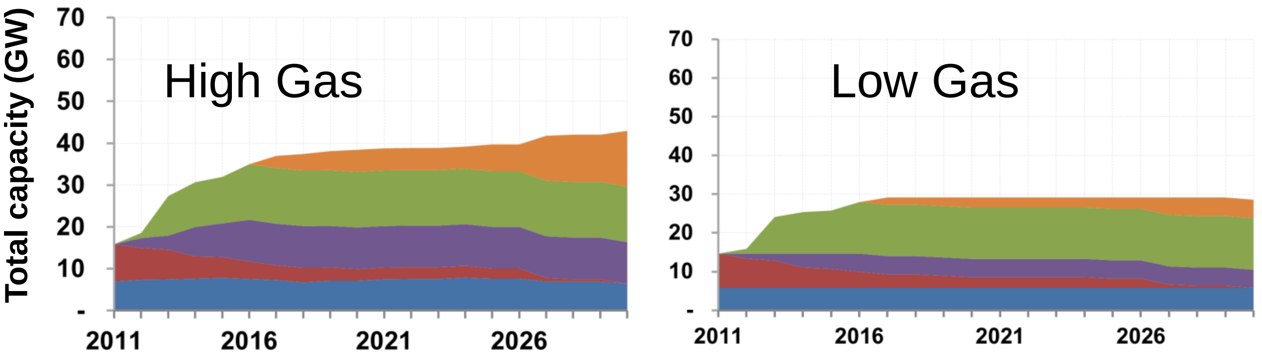
CCS feasibility of gas CCGT stock for slow, pragmatic and push scenarios



Italy has the highest gas CCGT stock. However, at 10% theoretical storage availability, if storage is reserved for industry and coal CCS, there is no spare domestic capacity for gas CCS. Thus cross border storage or exploration for additional offshore storage could be useful.

Germany

Stock of gas CCGT for High and Low gas under Pragmatic scenario



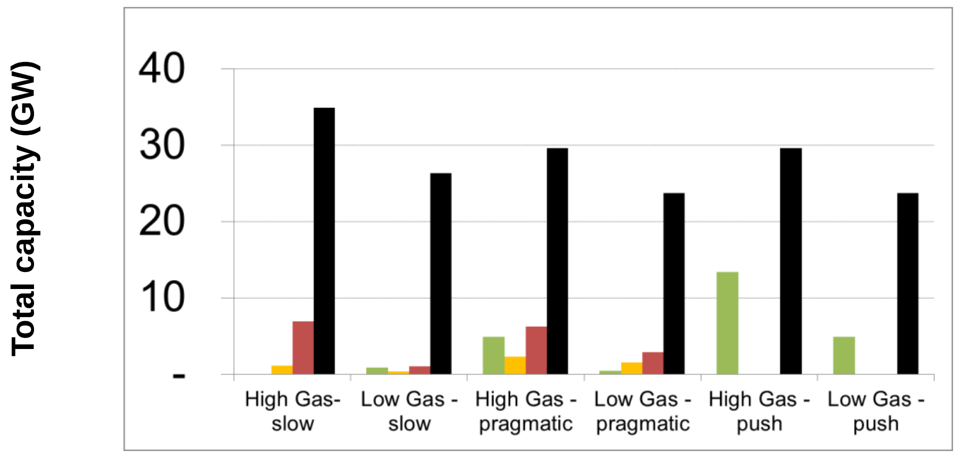
Capture ready | Known new build | Assumed repowered | Known operational | Less than 300MW

Map shows input CCGT locations:

Operational
Under construction
Planned

31 Gt theoretical storage

CCS feasibility of gas CCGT stock for slow, pragmatic and push scenarios

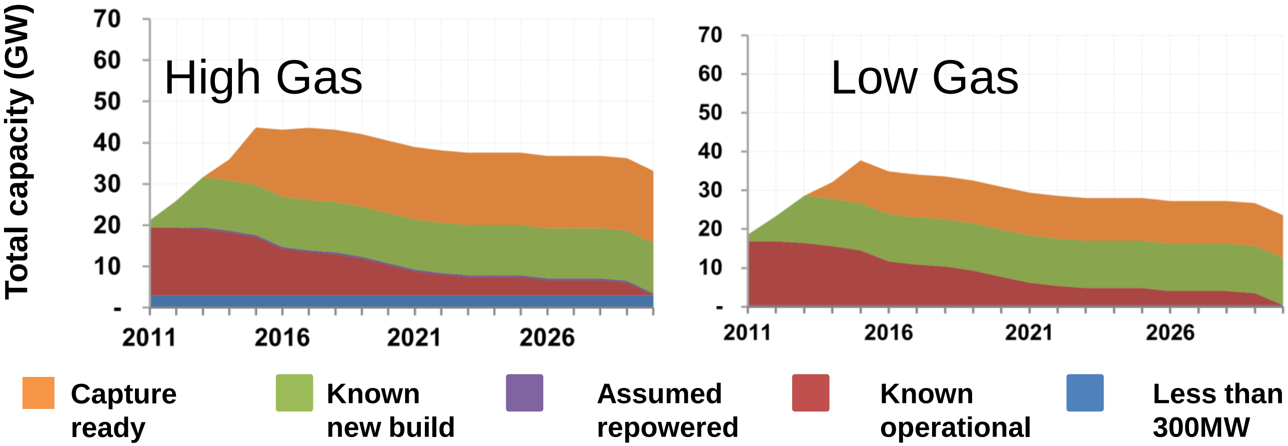


High | Medium | Low | Unready

Key challenges for Germany are capture readiness and storage. Onshore storage restrictions create a challenge, but even with onshore storage available this storage may be needed for industry and coal CCS, and therefore cross-border storage (e.g. to Norwegian sinks) is valuable.

UK

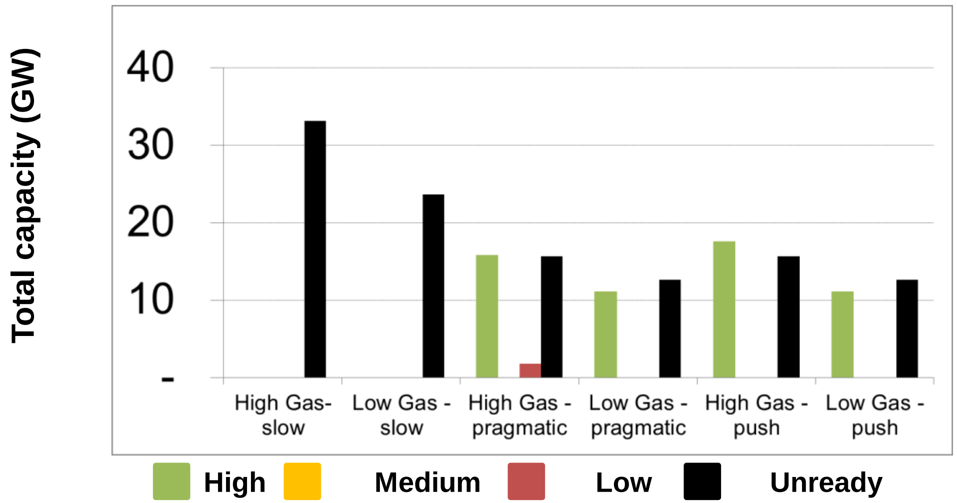
Stock of gas CCGT for High and Low gas under Pragmatic scenario



Map shows input CCGT locations:
Operational
Under construction
Planned

71 Gt theoretical storage

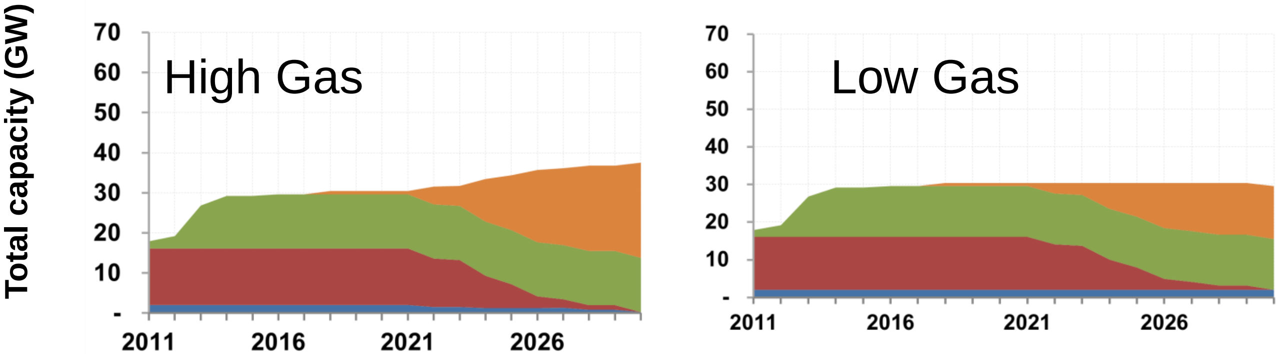
CCS feasibility of gas CCGT stock for slow, pragmatic and push scenarios



If early implementation of capture readiness, is undertaken, the UK is well placed to ensure gas CCS readiness as offshore storage is likely to be sufficient, even with coal and industrial CCS.

Spain

Stock of gas CCGT for High and Low gas under Pragmatic scenario

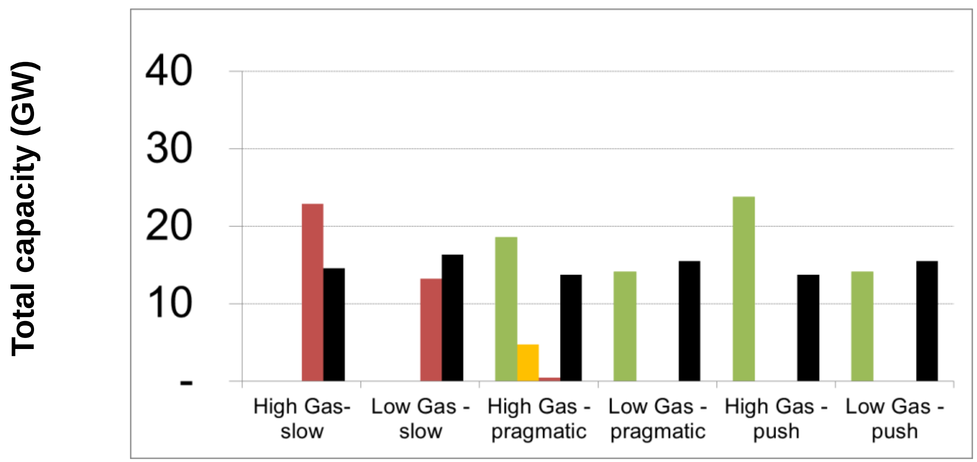


Capture ready **Known new build** **Assumed repowered** **Known operational** **Less than 300MW**

Map shows input CCGT locations:
Operational
Under construction
Planned

14 Gt theoretical storage

CCS feasibility of gas CCGT stock for slow, pragmatic and push scenarios

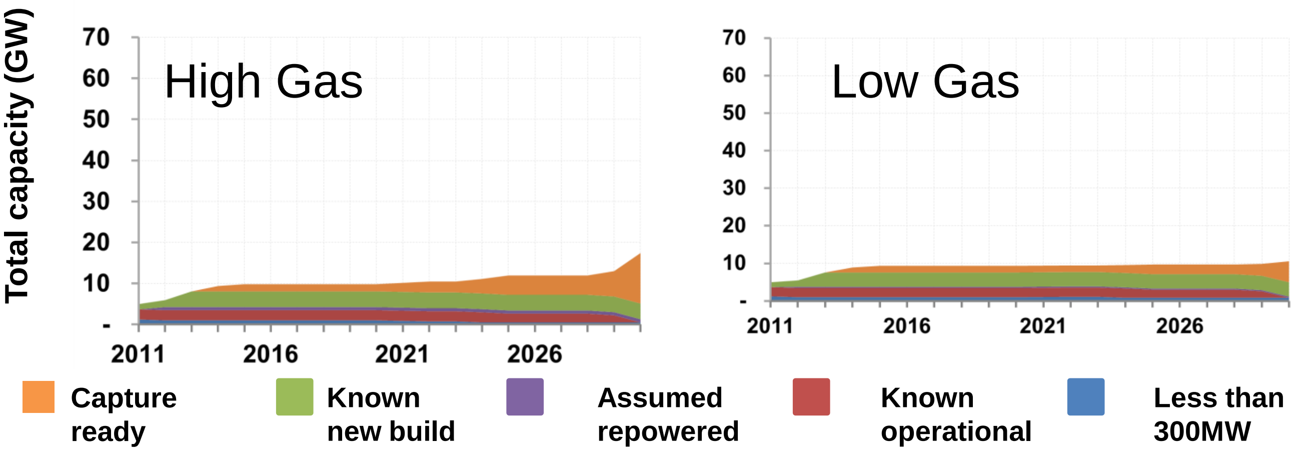


High **Medium** **Low** **Unready**

Assuming 10% domestic theoretical storage availability, and onshore storage allowed, Spain has high levels of CCS ready stock.
If onshore storage is restricted, a new search for offshore storage may be required – or alternatively long CO_2 transport networks would be required.

France

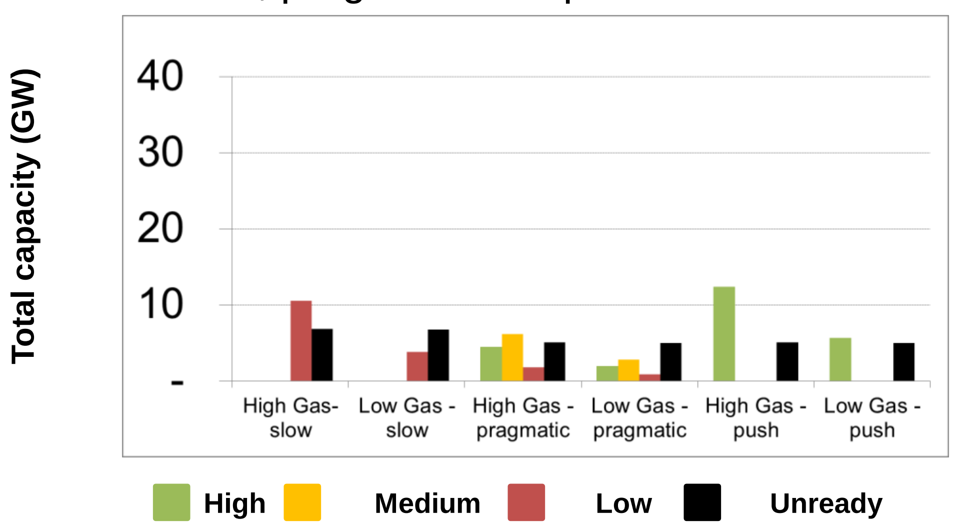
Stock of gas CCGT for High and Low gas under Pragmatic scenario



Map shows input CCGT locations:
Operational
Under construction
Planned

9 Gt theoretical storage

CCS feasibility of gas CCGT stock for slow, pragmatic and push scenarios



Assuming 10% of theoretical storage is bankable, and onshore storage allowed, in France there is high competition for storage from industry and coal CCS. Therefore further storage development and cross-border agreements would be required to increase gas CCS ready capacities.