CO_2 Storage Resource Catalogue

Cycle 3 Report

March 2022

Amounts of CO_2

Stored
0.0006 Gigatonnes

Commercial
0 Gigatonnes

Sub-commercial
57 Gigatonnes

Undiscovered
4275 Gigatonnes

Appendix B : Asia

Bangladesh
Brunei
China
India
Indonesia,
Japan
Kazakhstan
Malaysia
Pakistan
South Korea
Sri Lanka
Thailand
Vietnam

Contents

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Important notice

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Tables

1.0 Bangladesh, India, Pakistan, and Sri Lanka

1.1.1 Summary

Bangladesh, India, Pakistan and Sri Lanka were assessed during Cycle 1. The CSRC has identified CO_2 storage resources for Bangladesh, India, and Pakistan as follows:

Bangladesh

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	1.13	0
Undiscovered	20.0	0
Aggregated*	21.13	0

India

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	0.84	0
Undiscovered	63.3	0
Aggregated*	64.14	0

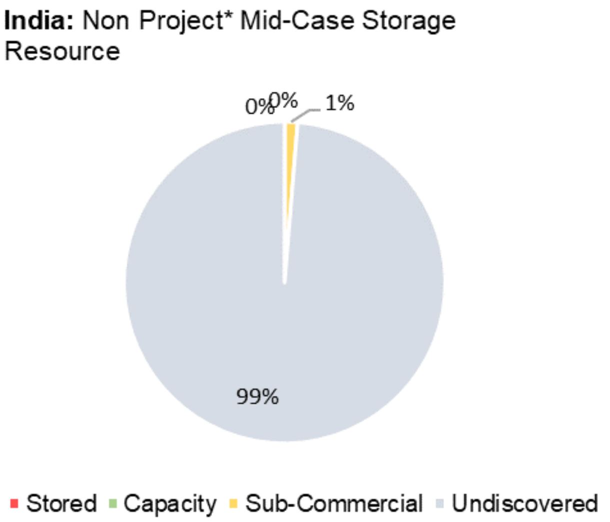
Pakistan

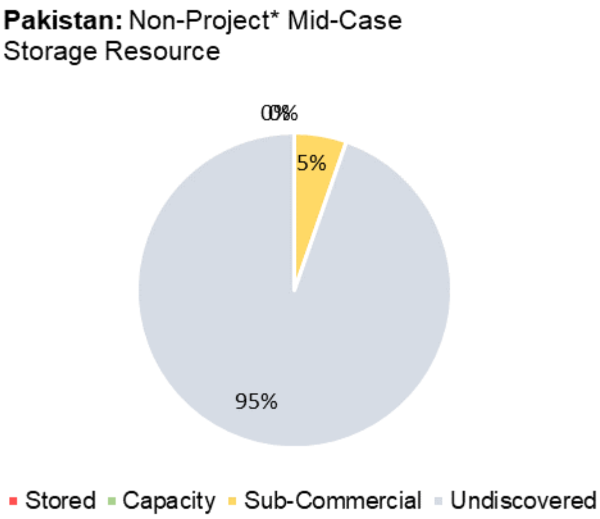
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	1.7	0
Undiscovered	30.0	0
Aggregated*	31.7	0

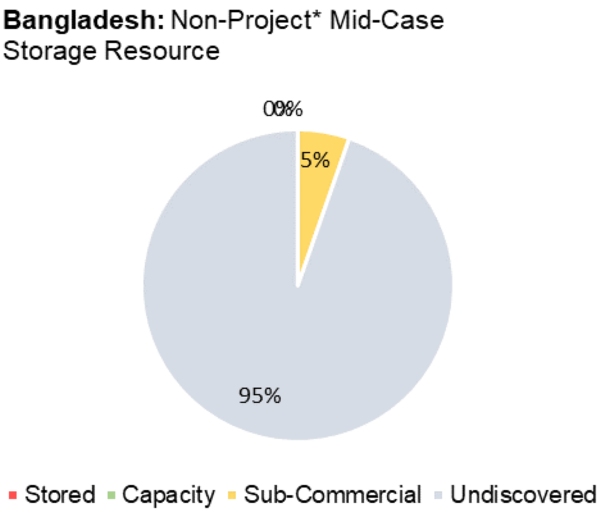
* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 1-1: Storage resource classification summary for Bangladesh, India and Pakistan

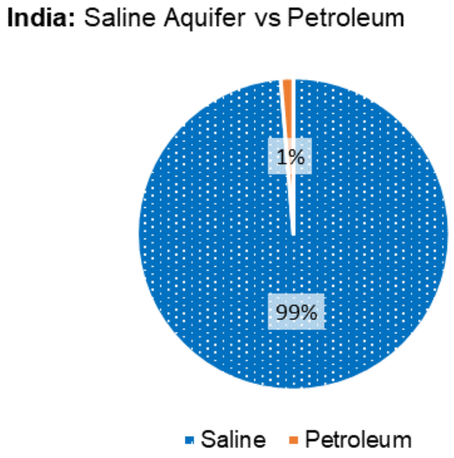
- Bangladesh has 23 sites in the CSRC: 1 saline aquifer (Undiscovered; 20.0 Gt) and 22 gas fields (Discovered; 1.13 Gt).
- India has 15 sites in the CSRC: 11 saline aquifers (Undiscovered; 63.3 Gt) and 4 oil and gas fields (Discovered; 0.84 Gt)
- Pakistan has 17 sites in the CSRC: 2 saline aquifers (Undiscovered; 30 Gt), 14 gas fields and 1 site representing 56 small oilfields (Discovered; summed resource 1.7 Gt).
- No resources in Sri Lanka were reported.
- All sites in Bangladesh, India and Pakistan are classed as "Inaccessible" for both the "Sub-Commercial" oil and gas fields and the "Undiscovered" saline aquifers due to the lack of a CCS regulatory framework in any of these countries. No projects are defined.
- There are no defined storage projects in the region.

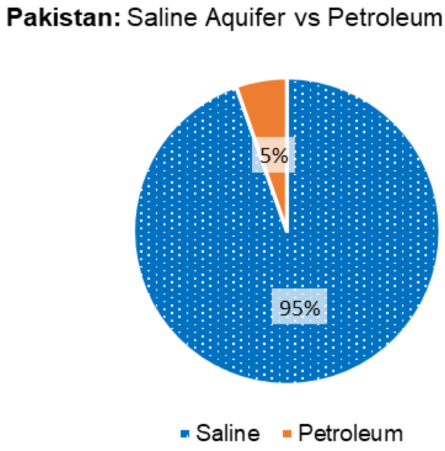






Note: No sites with a project specified were identified for India, Pakistan and Bangladesh.





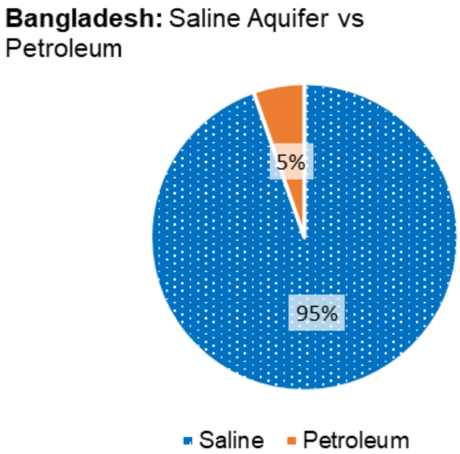


Figure 1-1: Above: Spread of all storage resource across SRMS classifications. Below: Split of storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

1.1.2 Resource Statement

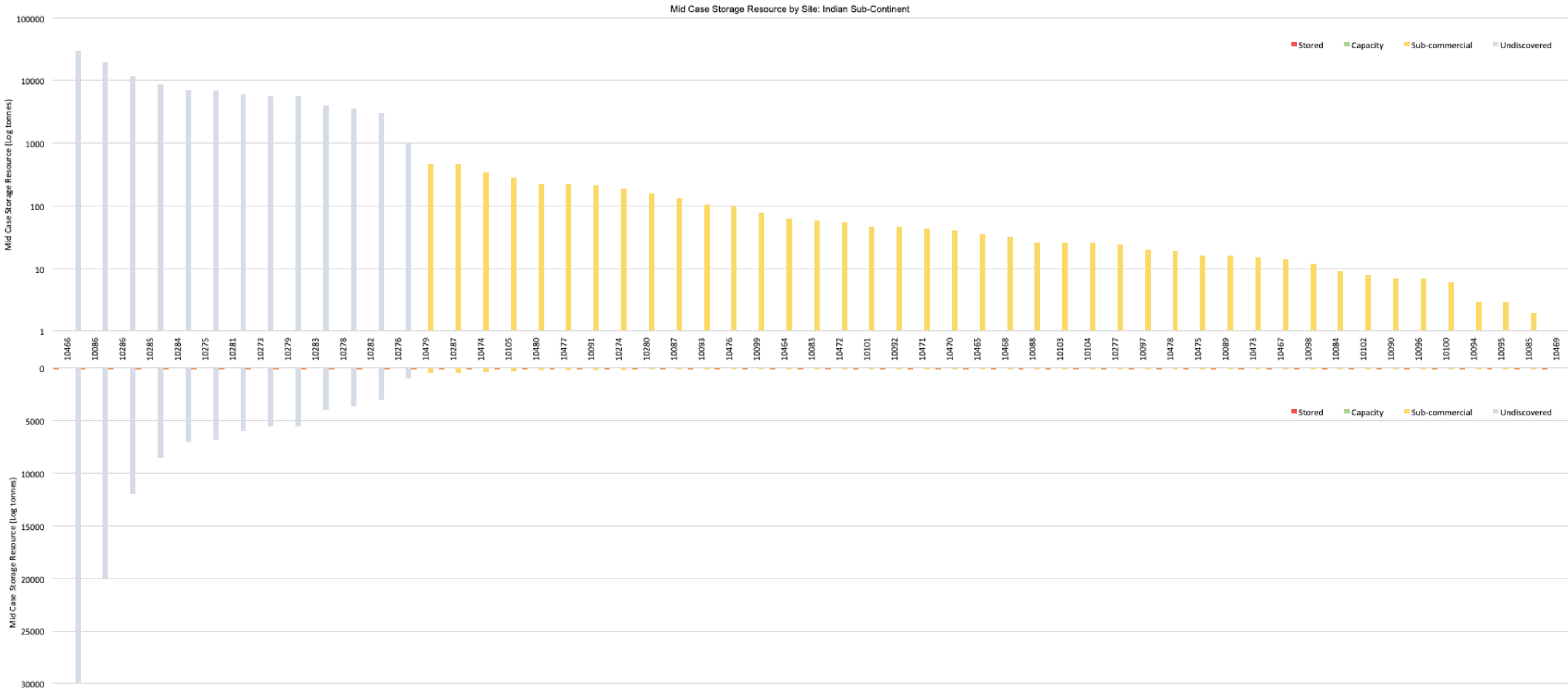


Figure 1-2: Storage resource summary for India, Bangladesh and Pakistan compiled in the CSRC. Graph above is log scale and graph below is linear. No project specified sites were identified.

1.1.3 Evaluation History

Bangladesh, India, and Pakistan underwent a preliminary assessment as part of the CSRC Cycle 1. A regional evaluation of the CO_2 storage potential of the Indian subcontinent was completed in 2008 by the British Geological Survey (BGS) on behalf of the IEAGHG [1]. Its purpose was an early-stage evaluation to gauge the potential for CO_2 storage in geological reservoirs across the region. It includes a review of all major emissions points of over 1Mt/yr. and considered depleted oil and gas fields, saline aquifers and deep unmineable coal seams. It excludes the potential storage resource within salt caverns and the subcontinents extensive basalt formations in the Deccan and Raajmahal Traps. The national storage potential of India, Pakistan, and Bangladesh were all evaluated independently. Although there is some evidence for offshore resource potential to the north and west of Sri Lanka, no resource base has been quantified at this time.

The BGS evaluation used the replacement method for calculating storage resource for depleted oil and gas reservoirs, but for India this has been based upon state-by-state petroleum reserves figures (excluding oil already recovered). Elsewhere, many fields had statements of projected ultimate recovery. Further challenges with data availability have resulted in reasonable assumptions having to be made about CO_2 density, water influx, gas production and oil properties. All these factors contribute to the assessment of potential storage resources in depleted oil and gas fields as being both "highly provisional".

For saline aquifer resource estimation, an analogue method has been adopted where it is assumed that the CO_2 storage resource potential could be estimated using the following assumptions:

1. That one or more deep saline aquifers suitable for CO_2 storage were present over 50% of the basin.
2. 0.2 x 106 tonnes CO_2 could be stored per km2 of the area above.

This equates the CO_2 storage resource potential in Mt as 10% of the basin area in square kilometres.

1.1.4 Resource Review

Overall, it is only possible to identify two classes of quantified CO_2 storage resource potential within the region:

- Depleted oil and gas fields - these have been classified as “Discovered” storage resource, but also as "Inaccessible" at this time due to the absence of a CCS regulatory system within any of the countries in the region.
- Saline aquifer systems - these have been classified as “Undiscovered” storage resources, although it is accepted that there will be a small number of wells drilled into these systems which establish discoveries, the location and details of these wells are not available within the regional assessment. Due to the absence of a CCS regulatory framework, the resources have been classified as “Inaccessible” at the time of assessment.

The regional assessment is an early and indicative assessment of storage resources. Over 95% of the stated resource is held within very poorly defined saline aquifers.

1.1.5 Regulatory Framework

None of the countries in this region have developed policies or CCS-specific regulatory or legal frameworks and only India has been evaluated under the GCCSI CCS Readiness framework. India is classed as a high opportunity country in that it would benefit from CCS deployment but has no system in place to encourage this. India has a legally non-binding CO_2 emissions reduction target of 20-25% by 2020. In its Mission Innovation submission India indicated its interest in CO_2 capture and utilization (CCU) beyond EOR but there has been no significant action from the federal government to advance its deployment.

1.1.6 Issues for the Assessment

There is currently little information available to build a true picture of the storage potential of any of the countries in the region. Where data are available, the depth and generally low quality of the information make assessment difficult and so several assumptions have had to be made during resource estimation.

As a result of the low maturity of the resource estimation, there is only a single value provided for each resource. This has been recorded as the 'Mid-Range' estimate of resource potential. As future studies are planned in the region, effort needs to be made to move towards generating probabilistic assessments.

1.1.7 Future Updates

1.1.7.1 Future CSRC cycles

Any update should be made as and when concrete, useful improvements to the understanding of storage potential in the region become available.

2.0 Brunei

2.1.1 Summary

Brunei was assessed during Cycle 3. The CSRC has identified a CO_2 storage resource for Brunei as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	0.00	0.00
Undiscovered	0.558	0.558
Aggregated*	0.558	0.558

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 2-1: Storage resource classification summary for Brunei.

- Storage resource evaluation is very limited in Brunei. A single study, evaluating the techno-economic potential across the APEC region identifies only a single formation.
- While potential for CO_2-EOR and EGR are briefly mentioned (the Cycle V formation ranks 6th for CO_2-EOR), only injection into the saline aquifer located below offshore gas discoveries is considered.
- Significant additional technical evaluation will be required to mature the resource potential in Brunei.
- No published CCS-specific regulatory framework or enabling legislation have been published to date.

2.1.2 Evaluation History

There has been very limited evaluation of CO_2 storage potential in Brunei. A single formation was included as part of a 2010 study for the Asia-Pacific Economic Region (APEC) looking at a techno-economic analysis of controlling CO_2 emissions in SE Asia.

2.1.3 Resource Review

2.1.3.1 Depleted Oil & Gas Fields

Basin screening was undertaken using a methodology based on that of Shaw and Bachu [2] and identified the Cycle V formation in the Baram Delta B basin in Brunei as ranking 6th of 17 formations for CO_2-EOR potential across the region. Potential for enhanced gas recovery using CO_2 injection for re-pressurisation was also discussed but no detailed studies performed.

2.1.3.2 Saline Aquifers

A high-level techno-economic study of CO_2 storage in saline aquifers co-located with gas fields was carried out. Simple reservoir simulations, based on reservoir properties from adjacent fields assumption of 10 km distance from gas discovery), were used to develop a basic storage development plan based on well number and projected injection rates given assumptions of CO_2 volumes and reservoir conditions. Injection of CO_2 (stripped from produced gas) was assumed to take place into a saline aquifer below the gas-producing formation. As such, this evaluation qualifies for inclusion in the Catalogue as it does not represent direct replacement of produced CO_2 in the gas field. CO_2 volumes are based on predicted production and removal from the sales gas while the CO_2 resource is based on the volume of CO_2 injected into the saline aquifer during multiple simulation runs.

The reservoir properties for the injection simulation are provided in the Catalogue database but it should be noted that this is a very high-level study which was focused on providing an indication of the costs of CO_2 capture and storage to allow monetisation of the gas discoveries across the APEC region. The technical evaluation of the actual storage resource is limited; more evaluation will be required to qualify and mature the resource further.

2.1.4 Regulatory Framework

As of Cycle 3, no CCS-specific regulatory framework exists in Brunei. The 2010 review by CO_2CRC [3] as part of the ASEAN assessment identified several laws related to environmental issues and noted that, while there was no specific legal requirement for the development of environmental impact assessments, there was a government requirement for such assessments for heavy industry projects. While it is possible that carbon storage projects could be enabled under existing legislation, particularly that covering the oil and gas industry, this has not yet been tested.

2.1.5 Issues for the Assessment

The extremely limited information in the public domain has restricted the assessment for Brunei. Future development of a pathway to reducing the high per capita CO_2 emissions of the nation may drive further evaluation (see 'Future Updates' below).

2.1.6 Future Updates

In January 2022 an agreement was signed on a CCS partnership in Brunei between Perdana Solutions Sdn Bhd and Asia Pacific Energy Solutions. The partnership is aimed at developing a CCS value chain and an action plan leading to implementation. Future cycles should follow any developments from this partnership.

3.0 China

3.1.1 Summary

China was assessed during Cycle 1 and was updated in Cycle 3. The CSRC has identified a CO_2 storage resource for China as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.0003	0.0003
Capacity	0	0
Sub-Commercial	10.5	0.03
Undiscovered	3067	0
Aggregated*	3077	0.03

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 3-1: Storage resource classification summary for China

- There is a total of 72 sites in the CSRC, largely at a regional scale or a high-level evaluation, with only two sites associated with a project. The storage resource is located across a minimum of 21 geological basins, both onshore and offshore.
- China boasts numerous CCUS projects, of which 8 of the key projects currently are, or will reach large-scale operations in the 2020s.
- Government policy has led to numerous pilot- and large-scale CCUS facilities being developed, however, this is largely to support enhanced oil recovery operations (EOR). The lack of CCS-specific legislation means more needs to be done to incentivise geological storage and true decarbonisation.

Figure 3-1: a) Spread of storage resource in Chinese sites (72) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Chinese sites across SRMS classifications; both project specified and not. c) Split of Chinese storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

3.1.2 Resource Statement

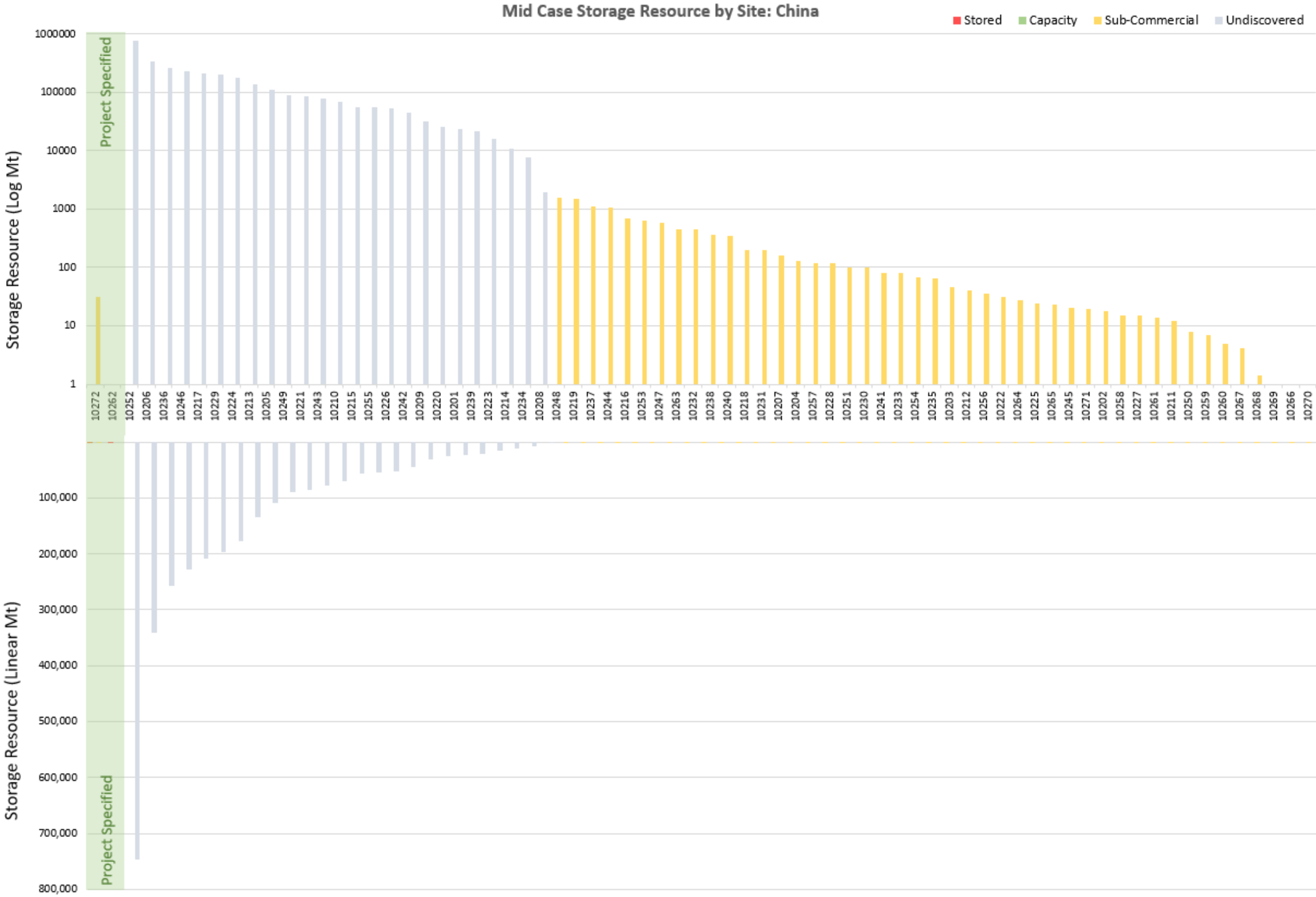


Figure 3-2: Storage resource summary for China compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

3.1.3 Evaluation History

The regional evaluation by the Pacific Northwest National Laboratory in 2009 [4], of the potential CO_2 storage resource available within the onshore and offshore territory of China was a first of its kind. It was produced as a collaboration between US and Chinese researchers and was commissioned by the US Department of Energy. The report evaluates a large and diverse geographic portfolio of potential CO_2 storage resource within oil and gas fields, deep saline formations and coal seams. It is only intended to provide a starting point for finer resolution analysis. The majority of the Chinese sites are sourced from this PNNL report.

The estimation of the storage resource within saline aquifers was considered only through theoretical calculation of 100% dissolution of CO_2 within reservoirs deeper than 800-1000m. Whilst acknowledging the clear potential for hydrodynamic and residual trapping, these storage mechanisms are not specifically included within the assessment. The authors PNNL suggest that this approach of ignoring the potential of "free CO_2" phase storage will result in a very conservative resource estimate.

For the evaluation of gas fields, a modified replacement method was adopted which assumes that only 75% of the pore volume once occupied by produced gas could be filled with CO_2. This would seem to make provision for some loss of storage efficiency perhaps resulting from water ingress into the reservoirs from underlying water leg.

Unlike the other regional assessments, the PNNL study only considers the storage in oilfields when linked to enhanced oil recovery. Instead of deploying a simple replacement method for the assessment of storage potential, the regional assessment has considered this potential using guidance and analogues from well-established CO_2 EOR provinces such as the West Texas area of the US. This together with pre-published assessments of initial oil in place for Chinese oilfields has enabled an initial assessment of potential storage resources associated with EOR to be made. It should be noted that the CO_2 EOR performance of the primary analogues is drawn from an environment where the oil producer must purchase CO_2 from a provider. As a result, the operators have become extremely efficient at using the purchased CO_2 inventory to optimise oil recovery. Of course, this approach also minimises CO_2 storage resource by definition and so this does represent a conservative view of potential storage resource.

The PNNL reported volumes are supplemented by the stored volume at the Shenhua Group CCS Demonstration project [5], plus theoretical storage resource evaluations for hydrocarbon fields within the Dagang oilfield complex [6].

3.1.4 Resource Review

3.1.4.1 Major Projects

China hosts a plethora of CCS and CCUS projects, ranging from pilot and demonstration right up to large-scale projects. Many of these projects are not well publicised and as such, this study may be an under-representation of the full scale of commercial and research operations currently being undertaken in China. The GCCSI (2018) recognises 18 key CCUS projects in China, including:

- 10 enhanced oil recovery (EOR) projects; 5 of which are demonstration projects and 5 of which are currently or are developing towards large-scale operations by the 2020s.
- 3 projects capturing carbon dioxide for use in industrial or beverage applications. 2 projects currently under evaluation. There are large-scale facilities with power and coal-to-liquids applications.

- 2 projects currently under evaluation. There are large-scale facilities with power and coal-to-liquids applications.
- 3 projects are dedicated geological storage servicing the power and coal-to-liquids industries. One of these projects came to completion in 2014.

As carbon utilisation is outside the scope of this study, only projects utilising permanent geological storage of CO_2 were considered in the CSRC These projects include:

Shenhua Group CCS Demonstration project in the Ordos Basin. It was the first deep saline aquifer storage in China. The project started in 2011, injecting 0.1 $MtCO_2$/yr until completion in 2014, reaching a total of 0.302 Mt CO_2 stored. The full-chain CCS project captured CO_2 from a coal liquefaction plant and injected the CO_2 into a tight carbonate reservoir using fracking to enhance secondary porosity.

China Resources Power (Haifeng) Integrated CCS Demonstration Project, Shanwei. A capture test platform has been running since 2018 capturing 0.025 Mtpa from the power industry, aiming to scale up to large-scale operations (1 Mtpa) in 2020s. Due to the small volumes, this project is not included in the website database.

Guohua Jinjie CCS Full Chain Demonstration, Shaanxi Province. Demonstration-scale operations capturing CO_2 from a coal-to-liquids facility at 0.15 Mtpa since 2017. Due to the small volumes and lack of publicly available literature, this project is not included in the website database.

3.1.4.2 Depleted Oil & Gas Fields

The natural gas fields represent a small portion of the storage resource in China, with an aggregated storage resource of 5.2 Gt. Similarly, oilfields comprise a more minor component, with an aggregated storage resource of 4.8 Gt for oilfields including EOR. Evaluations for dedicated geological CO_2 storage within oilfields, rather than CO_2 EOR, could only found for the Dagang Oilfield Complex. This highlights the need for the country-wide evaluation of hydrocarbon fields, to avoid the underestimation of storage resource, as detailed in 3.1.3.

All storage resource within depleted hydrocarbon fields is classified as discovered. As the SRMS classification places a significance on the presence of a CCS regulatory system for classification, the absence of such a system in China currently limits the classification of discovered resources to "Inaccessible". For the oilfields evaluated with EOR operations [4], however, the resource was classified as “Development Not Viable” as CO_2 injection for EOR can take place under existing petroleum regulatory systems.

3.1.4.3 Saline Aquifers

As in many countries, deep saline formations represent the largest storage target in China, with an Aggregated Storage Resource for Undiscovered sites in the CSRC of 3067 Gt [4]. The PNNL regional evaluation does not present any information regarding the discovery status or the geological formations of the potential CO_2 storage resource. As a result, the entirety of the saline aquifer potential has been classified as Undiscovered Basin Play, even though significant tracts of this potential resource will undoubtedly have been discovered through exploration for petroleum and groundwater resources.

A small volume (0.302 Mt) has been stored in the Shenhua Group CCS Project [5], while 31.4 Mt is classified as Discovered Inaccessible [7], due to the lack of a CCS-specific regulatory system in China. The evaluation by [7], uses simulation modelling to estimate the storage resource of the Donggou Formation, in the Junggar Basin, and represents one of only two sites in this CSRC report with a project specified. In a country where there are numerous

CCS and CCUS projects being undertaken, this highlights the lack of detailed published literature on the Chinese CO_2 storage resource.

3.1.5 Regulatory Framework

China has numerous pilot- and large-scale CCUS facilities supporting the cement, coal-to-liquids and steel industries. These have been developed through state-supported research and development funding. The GCCSI recognise the strong focus on government incentives for EOR activities but encourage a stronger emphasis to be placed to incentivising storage through policy and CCS-specific regulation [8].

3.1.6 Issues for the Assessment

The calculation of depleted oil fields in the PNNL report was only considered when in EOR applications, which not only contrasts the methodology of other regional reports, but also doesn't provide a true reflection of CO_2 stored, as described in 3.1.3. Indeed, due to these complications, EOR studies are out of the scope for the CSRC, however the values from the PNNL report were included, in the absence of other significant estimations.

3.1.7 Future Updates

3.1.7.1 Future evaluations

Further work for evaluators should focus on evaluation at a site or even formation level, to progress the maturity of the Chinese resource along the SRMS classification system. The current evaluations of Chinese storage provide an under-representation of the storage potential in China.

3.1.7.2 Future CSRC cycles

In the 2018 GCCSI review of Chinese decarbonisation facilities [9], two key projects are highlighted as planned operations:

- Shanxi International Energy Group CCUS, Shanxi Province. Planned large-scale facility aiming to capture 2 Mtpa in the 2020s from power generation.
- Shenhua Ningxia CTL, Ningxia Province. Another large-scale facility is planned to be operational in the 2020s, aiming to capture 2 Mtpa from the coal-to-liquids industry.

A further two projects are identified by [10] as ‘in preparation’ for geological storage:

- IGCC Clean Energy pilot-project in Lianyungang. Aims to capture 1 Mtpa using pre-combustion capture.
- Oxy-fuel combustion sequestration in Zhongyan Yingcheng of Hubei. The project aims to capture 0.1 Mtpa for storage in salt rock.

If evaluations for the above projects are published, they should be included in future updates to the CSRC.

A critique is provided in [11], on the status of CCUS policy in China in a recent paper, which could also be included.

4.0 Indonesia

4.1.1 Summary

Indonesia was assessed during Cycle 2. The CSRC has identified a CO_2 storage resource for Indonesia as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	2.46	0.00
Undiscovered	13.40	4.39
Aggregated*	15.86	4.39

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 4-1: Storage resource classification summary for Indonesia

- Storage resource potential (33 sites) is present in both saline aquifers and oil and gas fields, with saline aquifers accounting for 89% of Indonesia's storage resource. Six sites are considered 'projects'.
- Potential storage resource has been identified in 11 sedimentary basins, with published oil and gas storage resource available for seven basins.
- Due to the lack of regulatory framework for CCS, all storage resource for Indonesia is classified as *Inaccessible* under the SRMS.
- The only discovered resource for Indonesia is in oil and gas fields.
- One known pilot project, the Gundih CCS Pilot, has support through state research and development funding and from the state-owned company Pertamina. It is yet to undergo the design and construction phase. This shows that the government clearly has an interest in potentially growing the CCS industry.
- Indonesia has several high CO_2 gas fields, many of which were studied in the CO_2CRC (2010) [3] report, with their associated saline aquifers proposed for CO_2 injection sites. Please see Section 3.6.4 in the main report for a discussion on high CO_2 fields.

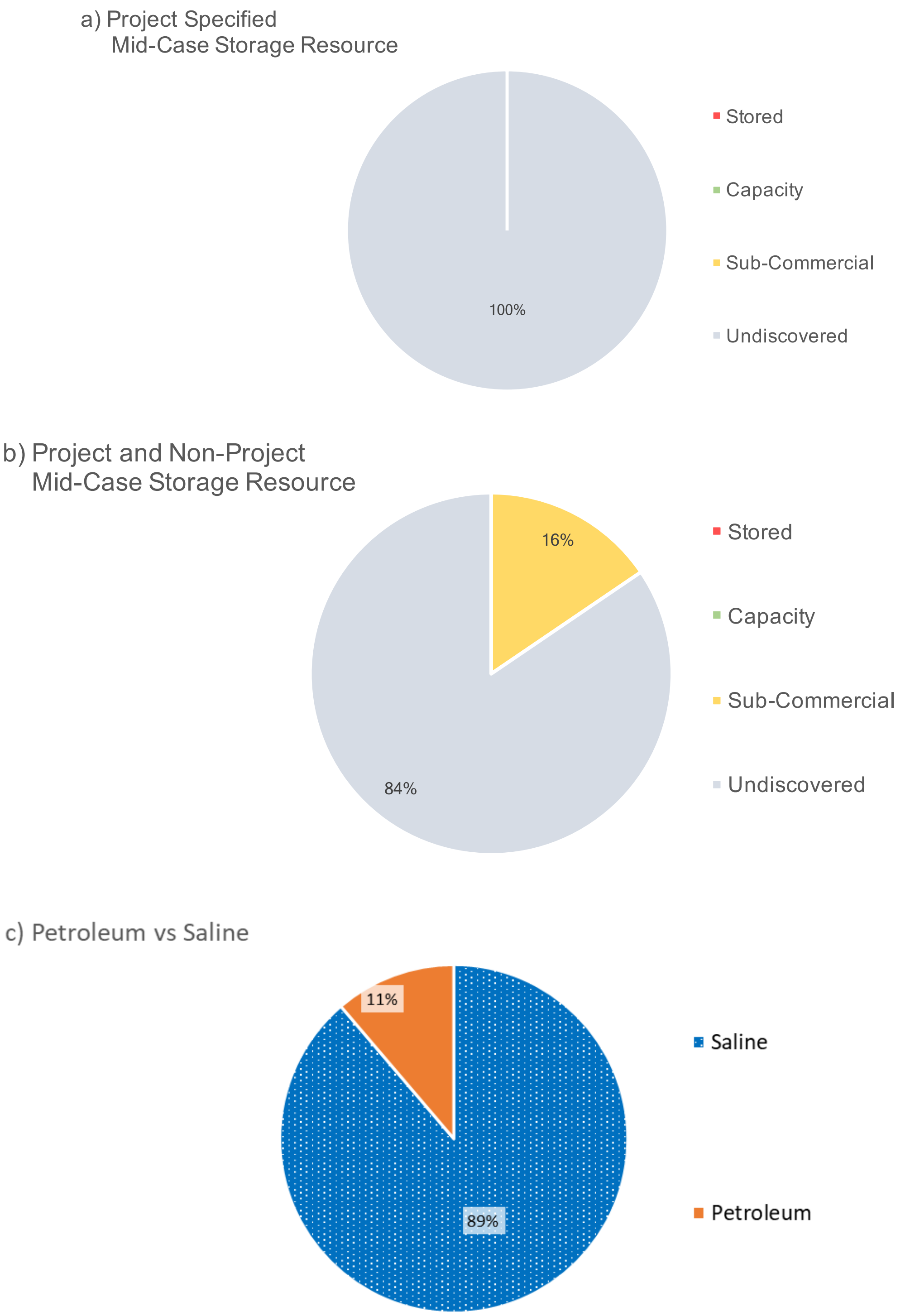


Figure 4-1: a) Spread of storage resource in Indonesia. Sites (33) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Indonesia. sites across SRMS classifications; both project specified and not. c) Split of Indonesia storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

4.1.2 Resource Statement

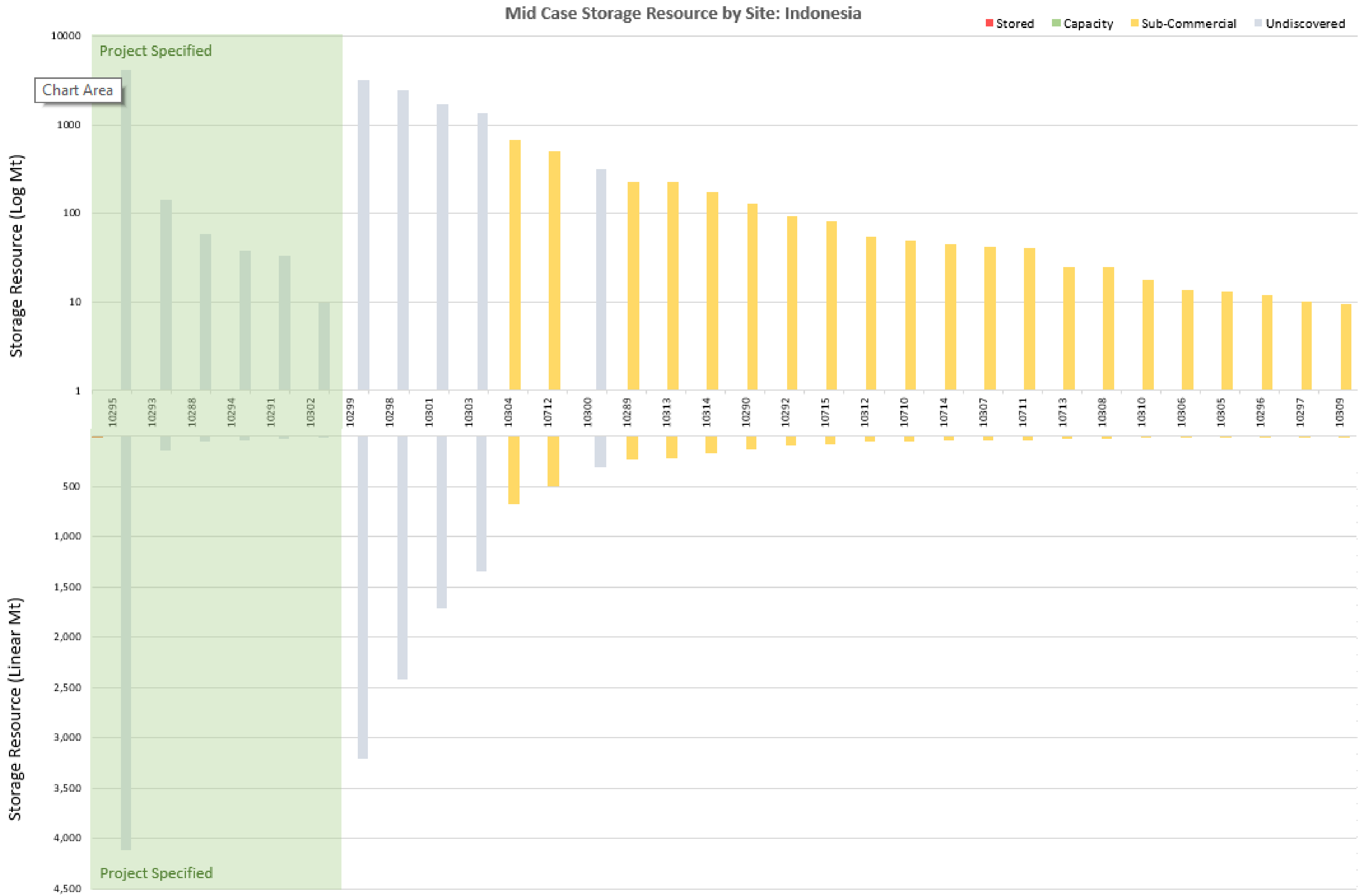


Figure 4-2: Storage resource summary for Indonesia compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

4.1.3 Evaluation History

The Cycle 2 storage resource assessment was based on five papers: Hedriana et al (2017) [12], World Bank (2015) [13], Iskandar et al (2013) [14], Asian Development Bank (2013) [15] and CO_2CRC (2010) [3]. All additional papers that were reviewed either provided no storage resource value, had been superseded by later studies, were based on CO_2-EOR or referred to the Gundih CCS Pilot, which is not included as a site in the CSRC as it is below the minimum threshold of 10 Mt.

Hedriana et al (2017) [12] built on the World Bank (2015) [13] study and both used equivalent approaches for calculating saline aquifer resource. The Hedriana et al (2017) [12] paper is more recent and uses a more realistic value for storage efficiency factor, therefore the saline aquifer resource from this paper was used in the CSRC.

The Asian Development Bank (2013) [15] report looked at a broad range of gas field resources in South Sumatra, which were split down to individual fields with attached resource numbers, and locations shown on a map. The World Bank (2015) [13] paper also includes a list of gas field resources in South Sumatra. The individual gas fields identified in the report have different names and resource numbers than the Asian Development Bank (2013) [15] report and do not appear to be duplicates so are included in the CSRC.

The CO_2CRC (2010) study for the Asia-Pacific Economic Cooperation [3] looked at high CO_2 gas fields and produced development plans for the saline aquifers associated with these fields. The resource values were included in the CSRC as projects.

4.1.4 Resource Review

4.1.4.1 Introduction

Indonesia has 11 sedimentary basins which have been identified (to date) as having storage potential and are included in the CSRC. Basin-wide saline aquifer resource data is available for the larger South Sumatra and West Java Basins, and smaller Bintuni, East Natuna, South and North Sumatra, and Kutai basins. Published data for depleted oil and gas storage is available for seven of Indonesia's sedimentary basins. Saline aquifers account for the majority (84%) of Indonesia's resource.

4.1.4.2 Pilot Projects

The only known pilot project in Indonesia is the Gundih CCS Pilot located in Blora district, Central Java province. Key players include Indonesia's state-owned oil and gas company Pertamina, the Ministry of Energy and Mineral Resources and the Asian Development Bank among others. The development plan is to capture CO_2 from the Gundih gas field and inject this into an uneconomic oil field at a rate of 30 tonnes per day. A total of 20 kt is to be injected during the two years of the project. According to the Global CCS Institute's database for pilot plants [16], the design and construction phase of the project is due to begin by the early 2020s.

4.1.4.3 Depleted Oil & Gas Fields

The only discovered storage resource in Indonesia are depleted oil and gas fields. The data coverage ranges from resources associated with individual fields to cumulative resources for entire basins. The South Sumatra Basin has resource values for 13 individual gas fields, which could be located on a map. The total resource between all 13 fields is 875 Mt, which is greater than any cumulative South Sumatra data that has been assessed. All together, these fields represent 49% of the discovered resource throughout the entire country.

Resource for the West Java Basin is divided into offshore and onshore fields and totals 395 Mt, representing 22% of the discovered resource.

All other basins do not have individual field values, the only subdivisions present are between cumulative oil fields and gas fields. Other basins with depleted oil field resource are: East Kalimantan, North Sumatra, South Sumatra and Barito. Other basins with depleted gas field resource: Salawati and North East Java. All these other basins hold a total resource of 528 Mt, 29% of Indonesia's discovered resource.

All oil and gas fields are classified as discovered, but inaccessible as the country has no regulatory framework present for CCS activities.

4.1.4.4 Saline Aquifers

As mentioned in the introduction, Indonesia has a small range of basin-wide saline aquifer data. All basin-wide storage resources exist within the South Sumatra and West Java basins – this is because they were included in multiple studies that aimed to identify sites for storage of CO_2 emissions from coal power stations in the area. Overall, three published values for each basin-wide resource were assessed, but only the resources from Hedriana et al. (2017) [12] were included as they were most recent, and in the case of south Sumatra, the values were more refined. The other two studies considered were a 2015 study by the World Bank [13] and a 2013 study by the Asian Development Bank [15]. There is a nulled entry in the storage assessment database to represent this.

The small saline aquifer sites mentioned above are associated with nearby high CO_2 fields [3] and represent 31% of the undiscovered resource. They are spread over five basins compared to just two for basin-wide resources. It should be noted that these sequence plays were only assessed based on their potential to store CO_2 from nearby high CO_2 gas fields. Therefore, they may not be in a good location, nor have the desirable properties for injection of anthropogenic CO_2 from power stations.

All saline aquifers are classed as undiscovered and inaccessible as the country has no regulatory framework present for CCS activities. If a regulatory framework became available, these resources would be promoted to the Basin Play and Sequence play maturity classes.

4.1.5 Regulatory Framework

Although Indonesia has a petroleum industry, there are not currently any laws specific to CCS. To deploy CCS in Indonesia, a legal and regulatory framework is required, however, the Global CCS Institute's CCS Readiness Index [8] states that "Indonesia is not taking the necessary steps to advance deployment at the required rate."

Due to this lack of regulatory framework for CCS, all storage resources for Indonesia are classified as *Inaccessible* under the SRMS.

The Gundih pilot project is yet to undergo the design and construction phase, but it has support through state research and development funding and from the state-owned company Pertamina. This shows that the government clearly has an interest in potentially growing the CCS industry. The Global CCS Institute's CCS Readiness Index also ranks Indonesia within the top 5 countries for inherent CCS interest, meaning that it has a high fossil fuel dependency and therefore will need CCS projects to meet future climate goals. Currently, interest in EOR projects appears to be greater than that for storage, since they provide financial incentives. The government needs to incentivise CO_2 storage through policy and CCS-specific regulation.

4.1.6 Issues for the Assessment

4.1.6.1 Oil and Gas Fields

The most recent data for gas fields in South Sumatra and West Java are given as cumulative basin numbers by Hedriana et al. (2017) [12], however the data in the CSRC are from World Bank 2015 [13] and Asian Development Bank (2013) [15] as these sources presented data for individual fields that could be located on a map. Therefore, the gas field data presented here is not the most recent but is the most refined.

The depleted oilfield storage that is given by Iskander et al. (2013) [14] does represent CO_2 storage as opposed to CO_2-EOR. However, due to the high incentives for EOR activities in the region, this can't be ruled out in any of these fields.

4.1.6.2 Saline Aquifers

To calculate the resource for the West Java Basin saline aquifer, the methodology presented in the World Bank 2015 report [13] used volumetric data from 15 gas fields before scaling up by a factor of 3 to represent the full extent of the basin. This is a different method than that which is used to calculate resource for most other saline aquifers.

In the CO_2CRC (2010) study for APEC [3], saline aquifers associated with high CO_2 fields were the planned CO_2 injection sites, and therefore included as storage resource in the CSRC. For each of these sites, a simple simulation was conducted to determine the maximum rate of CO_2 that could be injected over the injection period without the pressure in the reservoir exceeding its fracture pressure. Sensitivities were carried out on the number of wells required. Due to the sites having development plans, they have been included as projects in the CSRC.

4.1.7 Future Updates

4.1.7.1 Future Updates for Evaluators

- There is good detail on storage resource for depleted gas fields within the South Sumatra Basin, however the low resolution of the map images in the reports makes the field names challenging to read. For future evaluations, providing higher resolution map images is recommended.
- In other basins out with South Sumatra, acquiring, analysing and publishing new resource data that would divide up the cumulative depleted gas and oil field resource into individual field values with an attached location would be a good next step to mature the storage resource in Indonesia.
- For the West Natuna Basin, no data was uncovered in this cycle. The Natuna gas field and associated saline aquifer storage is East of Natuna Island and so not located within the West Natuna basin.
- The only basin wide saline aquifer data assessed in this cycle came from the West Java Basin, Java Sea Basin and the South Sumatra Basin. Future assessments should look to uncover basin wide saline aquifer resource data from other basins.

5.0 Japan

5.1.1 Summary

Japan was assessed during Cycle 2 and updated in Cycle 3. The CSRC has identified a CO_2 storage resource for Japan as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.0003	0.0003
Capacity	0.00	0.0
Sub-Commercial	36.23	0.03
Undiscovered	116.04	0.01
Aggregated*	152.27	0.04

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 5-1: Storage resource classification summary for Japan

Although storage resource is reported as being present in both saline aquifers and oil and gas fields, the greatest potential lies in saline aquifers.

- Evaluation of potential storage sites began in the late 1990's. Japan has developed one pilot project (10,000t) and one demonstration project (300,000 t) to date.
- Early studies reviewed sites using available data from hydrocarbon exploration ('Mission 1' study), follow-up evaluation of saline aquifers close to emissions sources ('Mission' 2 study) indicate significant storage potential, but the data are not readily available in the published literature.
- 25 sites with storage potential were identified in the Cycle 2 assessment, however only 13 have a storage resource estimate attached to it due to the difficulty in accessing data.
- The demonstration project, Tomakomai, is the first project in which CO_2 injection wells are directionally drilled from onshore to an offshore (subsea completion) injection point. Additional resource potential is available at the project site.
- Japan has no current CCS-specific current regulatory system, but CCS is embedded in its long-term Low Emissions Development strategy. The Tomakomai demonstration project was permitted using existing laws.

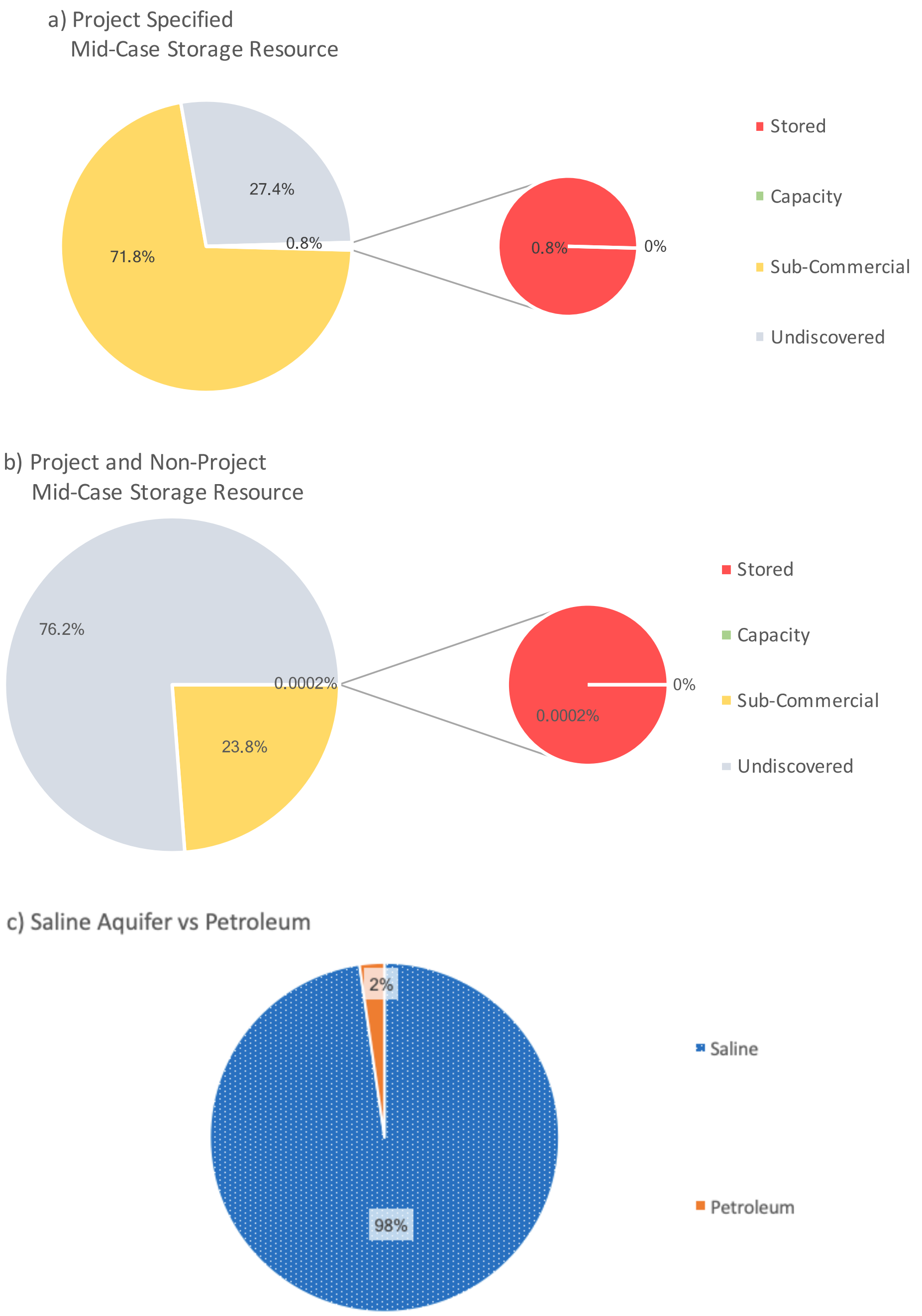


Figure 5-1: a) Spread of storage resource in Japan. Sites (25) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Japan. sites across SRMS classifications; both project specified and not. c) Split of Japan storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

5.1.2 Resource Statement

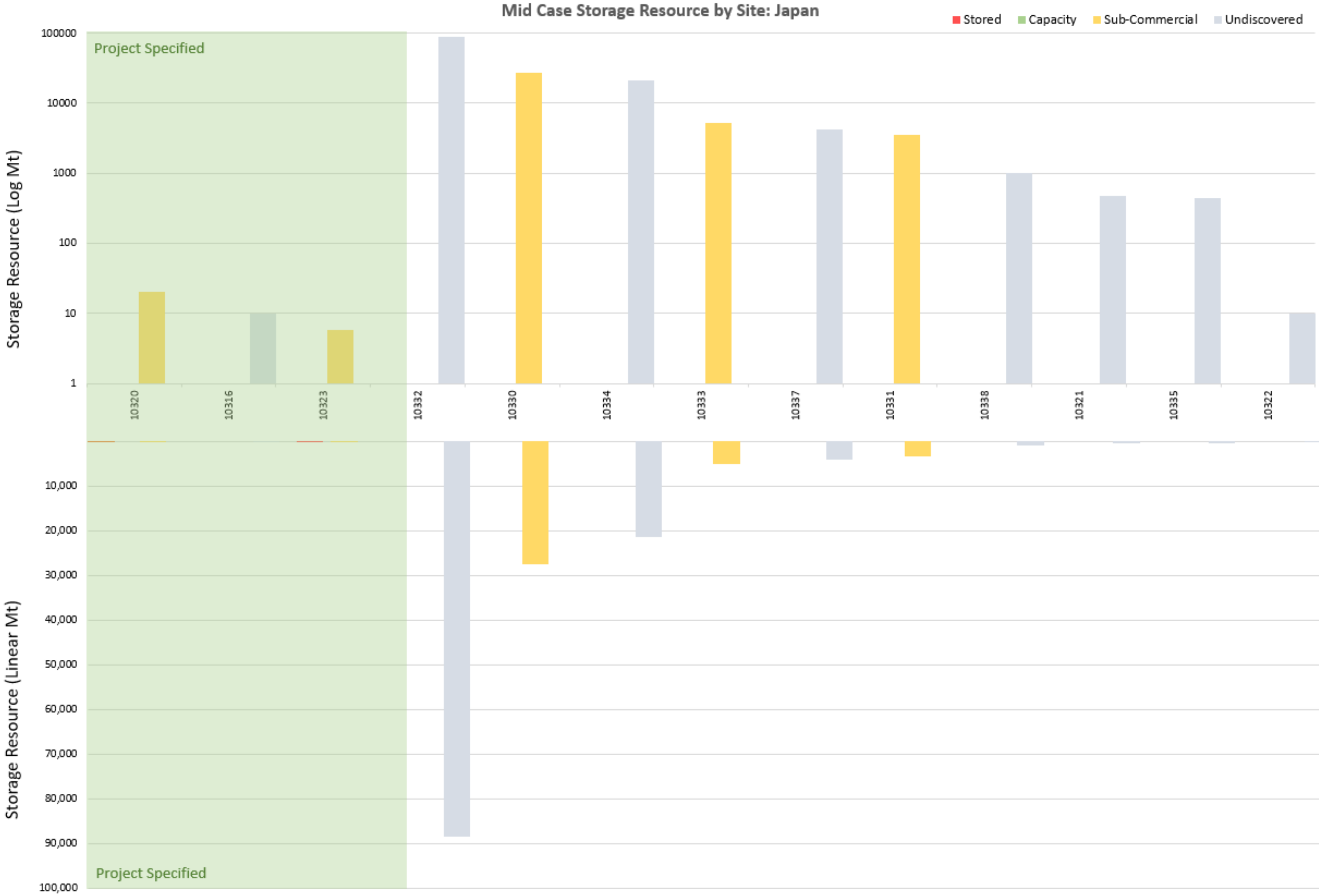


Figure 5-2: Storage resource summary for Japan compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

5.1.3 Evaluation History

Evaluation of potential storage resources in Japan began in the mid-nineties with an initial review of the storage opportunity using available hydrocarbon exploration and field data. All identified sites were subdivided by trapping style, data availability, and whether injected CO_2 could be 100% dissolved. A volumetric -based estimate of 91.5 Gt storage resource was published [17]. This initial review was followed by a 5-year national R&D project, 'Underground Storage of CO_2', which was then extended in 2005 to cover site selection for large-scale demonstration projects and future commercial projects. 'Mission 1' of the national project involved the Research Institute of Innovation Technology for the Earth (RITE) and the Engineering Advancement Association of Japan (ENAA) publishing a review of the 1995 data and an updated (volumetric) storage resource of 146.1 Gt [18], although the storage efficiency factors used are considered high (25% for structural traps; 12.5% for stratigraphic traps and open aquifers). 'Mission 2' studies continued the storage review work but focused on non-hydrocarbon-bearing basins close to major CO_2 emission sources (areas not covered by the Mission 1 studies). This work was used to build a database of 'promising areas' [19]. This Japanese language database is not readily available in the public domain, although attempts have been made to access the data during this 2020 Cycle (see 'Future Work'). Ogawa et al. [20] describe 27 candidate storage aquifers of which between 14 and 17 were down selected for detailed (although still at a regional level) study. In the absence of access to the Mission 2 database, estimates of storage potential in this assessment cycle are derived from a published bubble plot [20].

In 2008 [21] a comprehensive evaluation of potential storage sites identified 3 candidate sites: Nakoso-Iwaki Oki, a depleted gas reservoir 40km off the east coast of Honshu; Kitahyushu, a saline (open, no structure) aquifer; and Tomakomai, a pair of saline aquifers with some closure. Following the Great East Japan Earthquake, the Iwaki-Oki site was no longer considered as a candidate site. The Kitakyushu site was under a very early stage of evaluation having only limited 2D seismic data available. The more data-rich (3D seismic and 2 survey wells available) Tomakomai site was selected as Japan's first CCS Demonstration project.

In 2017, Japan CCS Co. Ltd. was commissioned by the Ministry of Environment (MOE and the Ministry of Economy, Trade and Industry (METI) to conduct an 'Investigation of Potential CO_2 Storage Sites' with the aim of selecting prospective sites by around 2021. At the Miakwa project (coal or biomass-fired power station), the search is underway to identify and evaluate potential transport and storage options for the project. The JCCS project is thought to be linked to this effort.

First deployment of CCS occurred at the pilot Nagaoka Project (2003 – 2005 where 10,400t CO_2 was injected into an onshore saline aquifer. This was followed by a successful demonstration scale project at Tomakomai.

As of 2020, Japan has a GCCSI Indicator score of 71/100 [22], an evaluation of a country's geological storage potential, maturity of their storage assessments and progress in the deployment of CO_2 injection sites.

Additional studies which provide discussion and storage estimates for microbubble CO_2 storage in Japan have not been included in this assessment cycle on the basis that they represent a more unconventional and untested approach to storage.

5.1.4 Resource Review

Although there is some identified storage potential in depleted fields in Japan (3.5 Gt), most of the storage resource potential lies in saline aquifers in the Neocene section of the subsurface; the older, deeper geological section is considered too structurally complex for CO_2 storage [23] [24].

5.1.4.1 Major Projects

Following the success of the pilot Nagaoka project, the Tomakomai Demonstration Project, operated by Japan CCS Co. Ltd., commenced in 2012 and ran until late 2020. Tomakomai and Nagaoka remain the only projects in Japan to have injected CO_2 for storage purposes.

At Tomakomai (Hokkaido Prefecture), gaseous CO_2 (99% purity) sourced from a hydrogen production unit (pressure swing adsorption off-gas) at an oil refinery near the port area is injected 3-4 km offshore into 2 offshore saline aquifers via 2 reservoir-dedicated, deviated injection wells. Between April 2016 and November 2019 300,110 tonnes CO_2 (approximately 100,000t/year) was injected for permanent storage. Extensive post-injection monitoring will continue. The majority (300,012t) of the CO_2 has been injected into the higher permeability Moebetsu Formation (1.1km subsea), with only 98t injected into volcanic rocks of the Takinoue Formation (2.7km). CO_2 injection was not impacted by the 2018 Hokkaido Eastern Iburi Earthquake. Current dynamic models indicate that up to 5.73 Mt CO_2 may be injected into the Moebetsu Formation using the existing injection well, while the Greater Moebetsu Formation is calculated (volumetric method) to hold a storage resource in the region of 486 Mt (P50; [24]). Future development plans include looking at the potential for using Tomakomai as a storage reservoir for CO_2 from other emission sources across Japan (Tanaka, *pers.comm.).*

A new pilot project, the Miakwa Pilot, broke ground in 2018. The Miakwa Power Plant is a biomass fed plant where over 500t CO_2/day will be captured and stored (making it carbon negative). The storage site for the pilot has yet to be determined but potential sites are being reviewed, including those involving transport of the captured CO_2 to distant locations.

5.1.4.2 Depleted Oil & Gas Fields

No detailed review of storage potential in depleted oil and gas fields is available in the public domain. Both Tanaka [17] and Takahashi et al [18] used data derived from hydrocarbon activities, which included oil and gas exploration data, with Takahashi et al. reporting 3.5 Gt total storage potential in 13 unnamed oil and gas fields. The offshore Iwaki-Oki depleted gas field (ceased production in 2007) was a candidate site for a demonstration project [21] with a numerically simulated 20Mt potential resource (at an injection rate of 1 Mt/year), but further evaluation and consideration was discontinued following the 'Great East Japan Earthquake', in 2011. Other technical issues including low reservoir pressure and legacy wells were also considered problematic. An additional 27.5 Gt is reported in onshore dissolved gas fields by the same authors. The large (368 BCM) Southern Kanto gas field is included in this resource, but no further breakdown of these storage resources is available in the public domain.

5.1.4.3 Saline Aquifers

Both Mission 1 and Mission 2 evaluated the storage potential on non-hydrocarbon bearing saline aquifers across Japan. The Mission 2 study (as reported in Ogawa et al. [20] focussed on areas close to major emission sources, with particular focus on Tokyo Bay, Ise Bay, Osaka Bay and Northern Kyushu. Of these, a more detailed evaluation of Osaka Bay and, to a more limited extent, Tokyo Bay are published, but are still on a regional scale. In addition to these areas, an additional 10 or 11 areas (out of the total 27 areas reviewed) were reviewed to assess the accuracy of the volumetric estimate of storage. Analyses of data availability and quality were made but unfortunately actual target formations and calculated resource estimates are only provided for 3 areas. All other estimates have had to be derived from a ‘bubble’ plot which limits the accuracy of the Catalogue data entries.

The volumetric resource calculation methodology uses a ‘storage factor’ derived from the ratio of immiscible CO_2 plume volume to total plume volume which, when multiplied by a value for the supercritical CO_2 gas phase volume fraction of the injected plume is considered to equate to the US DOE [25] ‘storage efficiency factor’. However, in the examples published, the storage efficiency equivalent factor was an optimistic 12.5%, almost certainly resulting in an overestimation of the storage resource estimate (US DOE, [25] P50 confidence interval storage efficiency factor for clastic reservoirs is 2.0%.

The estimated resource total for these Mission 2 aquifers is in the region of 23.9 Gt but care should be taken with this figure for the reasons described above. If a 2% storage efficiency factor were used the total resource estimate would be closer to 4Gt.

5.1.5 Regulatory Framework

In the 2018 GCCSI CCS Readiness Index [8], Japan ranked as a ‘Progressive Nation’, or one which is actively advancing deployment of CCS in the country but still has some ‘gaps in legislation policy and/or storage resource development which must be addressed before widespread deployment can proceed’. As of 2020, Japan has no CCS-specific regulatory system. However, it has continued to be a leader in future clean energy development. Japan is one of 15 countries which includes CCS in a long term low GHG emission development (LED) strategy under the UN Framework Convention on Climate Change (UNFCCC) [22]. CCS is embedded in the countries 2020 Environmental Innovation Strategy with an expectation that CCS will contribute 14% of cumulative CO_2 reduction by 2060. Japan also has the stated aim of being carbon neutral by 2050. Regulatory precedent is held through the CO_2 stored by the Nagaoka (pilot) and Tomakomai (demonstration) projects under the current regulatory system. To permit the Tomakomai project Japan amended a domestic law reflecting the London Protocol (1996) and awarded a 5-year permit allowing offshore storage of CO_2 but required an accompanying marine environment survey plan [26].

5.1.6 Issues for the Assessment

Lack of ready access to site-specific data was the main issue for this assessment cycle. Since 1995 Japan has undertaken several country-wide evaluations of storage potential however much of the detail of these is not in the accessible public domain. This means that the Catalogue risks an underestimation, or at a minimum a poor representation, of the details of the available resource.

5.1.7 Future Updates

5.1.7.1 Future CSRC cycles

Should any further development at the Tomakomai storage system occur, this should be reviewed on an annual basis to ensure the Global Storage Catalogue is up to date.

The RITE/ENAA storage resource database could provide additional, in-depth resource summaries which are currently not readily available in the public domain. If Japan CCS Co. Ltd. publish the results of their 2017 study ‘Investigation of Potential CO_2 Storage Sites’, any new sites should be added to the Catalogue.

6.0 Kazakhstan

6.1.1 Summary

Kazakhstan was assessed during Cycle 3. The CSRC has identified a CO_2 storage resource for Kazakhstan as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	1.17	0.00
Undiscovered	581.71	0.00
Aggregated*	582.88	0.00

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 6-1: Storage resource classification summary for Kazakhstan.

- Kazakhstan has no identified CCS projects, but has 20 storage sites in the CSRC.
- Oil and gas fields were assessed for CO_2 storage and are determined to be "Discovered: inaccessible" because the fields are assumed to be discovered with drilled wells and no regulatory framework for CCS exists in Kazakhstan.
- Saline aquifers were assessed for CO_2 storage and are determined to be "Undiscovered: inaccessible" because no information was provided regarding drilled discovery of the aquifer resources and no regulatory framework for CCS exists in Kazakhstan.
- Kazakhstan currently has no defined CCS projects.

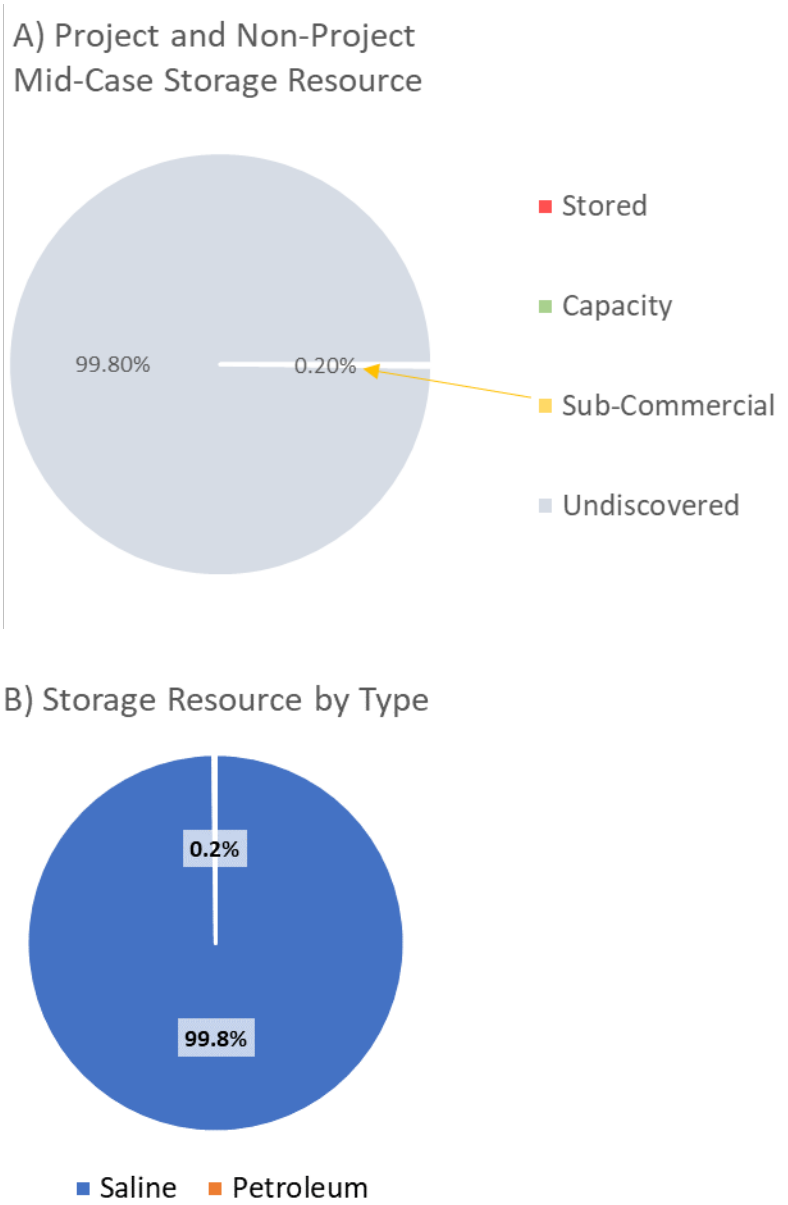


Figure 6-1: a) Spread of storage resource in Kazakhstan. Sites (20) across SRMS classifications; both project specified and not. b) Split of Kazakhstan storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

6.1.2 Resource Statement

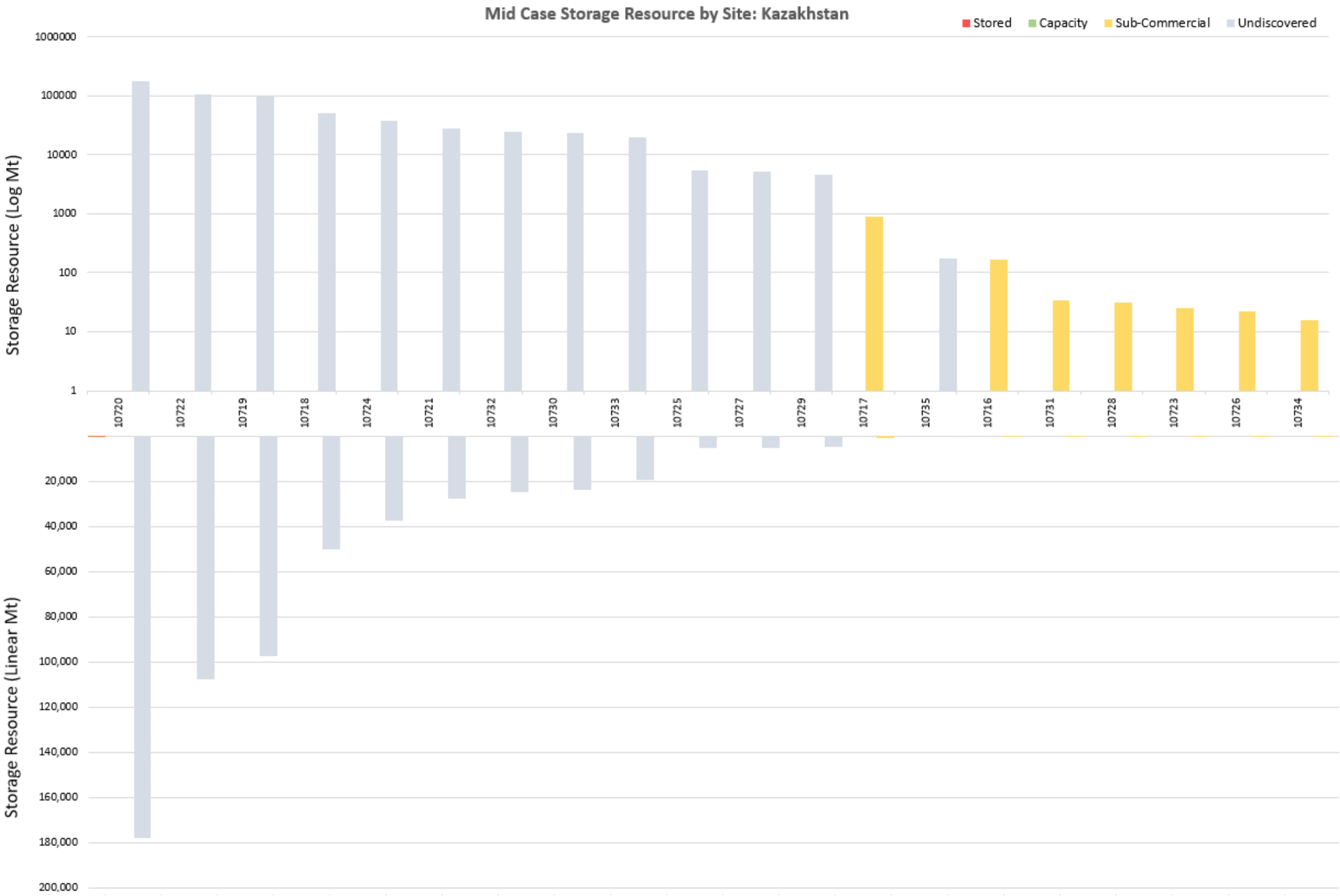


Figure 6-2: Storage resource summary for Kazakhstan compiled in the CSRC. Graph above is log scale and graph below is linear.

6.1.3 Evaluation History

Kazakhstan has significant oil and gas resources, on the order of 30 billion barrels – similar in scale to those of Libya and Nigeria [27]. Abuov et al. [28] considered both depleted oil and gas field storage resources and saline aquifer storage resources in their recent characterization of Kazakhstan's six most suitable sedimentary basins. While their resource characterization is high-level and regional in scale, the significant volume of subsurface geological data and discovered hydrocarbon resources in Kazakhstan provides a preliminary picture of the country's substantial geologic storage resource base.

Apart from this study, very little has been published on Kazakhstan's geologic storage resources.

6.1.4 Resource Review

6.1.4.1 Major Projects

Kazakhstan has no announced CCS projects of any size.

6.1.4.2 Depleted Oil & Gas Fields

Abuov et al. [28] estimate storage resources in Kazakhstan's depleted oil and gas fields utilizing the Carbon Sequestration Leadership Forum (CSLF) approach, which assumes that volumes previously occupied by hydrocarbons will be available for CO_2 storage. Basin-level storage parameters used in the authors' calculations were provided in the appendices to their paper. Only basins exceeding 10 Mt of storage resources are included in the CSRC. Results of this study show the Precaspian Basin is evaluated as containing – by a significant amount – the largest amount of storage resources in depleted oil and gas fields in the country. The Precaspian basin is assessed at 875 Mt. The authors did not present formation-level analysis for depleted oil and gas fields.

6.1.4.3 Saline Aquifers

Abuov et al. [28] estimate storage resources in Kazakhstan's saline aquifers utilizing the US Department of Energy (USDOE) approach, which employs a storage efficiency factor accounting for the fraction of the total pore space with which the injected CO_2 will come into contact. Compared to their study of resources in depleted oil and gas fields, the authors take a more detailed approach in assessing the country's saline aquifers, partitioning calculations by geologic age at the sequence-level.

According to these authors, the Precaspian Basin has, by far, the largest saline storage resources available in the country – approximately 460 Gt. These resources are distributed amongst five reservoir intervals ranging from the Carboniferous to the Cretaceous, in both clastic and carbonate lithologies. Saline aquifer storage resources in the other evaluated basins are an order of magnitude lower, ranging from ~44,000 Mt in the Mangyshlak Basin, down to just 176 Mt in the Zaysan Basin. The Zaysan basin situated on a transform continental boundary, is seismically unstable, and is therefore not considered suitable for storage.

The Precaspian basin has the largest storage resource base in Kazakhstan, across both depleted oil and gas fields and saline aquifers. It is unclear at this time if this is the case due to favorable geological characteristics or if this is simply an artefact of data density and availability for this basin relative to the other Kazakhstan basins evaluated by Abuov et al. [28].

6.1.5 Regulatory Framework

While Kazakhstan has ratified both the Kyoto Protocol, the UNFCCC Paris Agreement, and established an emissions trading scheme (ETS), the government has not yet established a CCS-specific regulatory or legal framework which would enable storage of CO_2 or encourage private investment in CCS projects.

6.1.6 Issues for the Assessment

Very little subsurface data is publicly available for Kazakhstan, so although the CO_2 storage potential in the country is likely high (indicated by this evaluation by Abuov et al. [28] and implied by its significant hydrocarbon resources), a comprehensive picture of Kazakhstan's CO_2 storage resources remains unclear.

The resources assessed in this cycle provided very little or no information about CCS projects, individual storage sites, or storage formation parameters. Reported masses of CO_2 (as presented by Abuov et al. [28]) for oil and gas fields are classified as discovered resources but we assume those fields have been penetrated by drilled wells. These resources will remain classified as Discovered: Inaccessible until the country establishes a legal regulatory framework for CCS projects. Due to the lack of published subsurface detail, saline aquifers are assumed to have not been defined by drilling and are therefore classified as Undiscovered resources. To mature these saline aquifer assessments into the Discovered classification, more information is required, such as locations of well control.

6.1.7 Future Updates

6.1.7.1 Future Evaluations

More detailed analysis is required to mature Kazakhstan's storage resources toward commerciality, for both saline aquifers and depleted oil and gas fields. Geologic models including simulation of injection projects should be completed for proposed storage sites utilizing well and seismic data to constrain model dimensions and subsurface architecture. In order to fully understand the CO_2 storage resources of the Kazakhstan, all possible sites need to be characterized and assessed.

6.1.7.2 Future CSRC cycles

Updates to this Cycle 3 assessment should be completed if additional studies on Kazakhstan's storage resources become available.

7.0 Malaysia

7.1.1 Summary

Malaysia was assessed during Cycle 2. The CSRC has identified a CO_2 storage resource for Malaysia as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.0	0.0
Capacity	0.0	0.0
Sub-Commercial	0.0	0.0
Undiscovered	149.6	0.10
Aggregated*	149.6	0.10

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 7-1: Storage resource classification summary for Malaysia

- Malaysia has six sites in the Cycle 2 Assessment: two basin scale saline aquifers (undiscovered) and one project where the resource will be used to store CO_2 that is co-produced with natural gas (undiscovered).
- All sites are undiscovered as there is no published information on wells that may have been drilled in the formation.
- In the absence of any CCS-specific regulatory system, all resources are currently classified as ‘Inaccessible’.

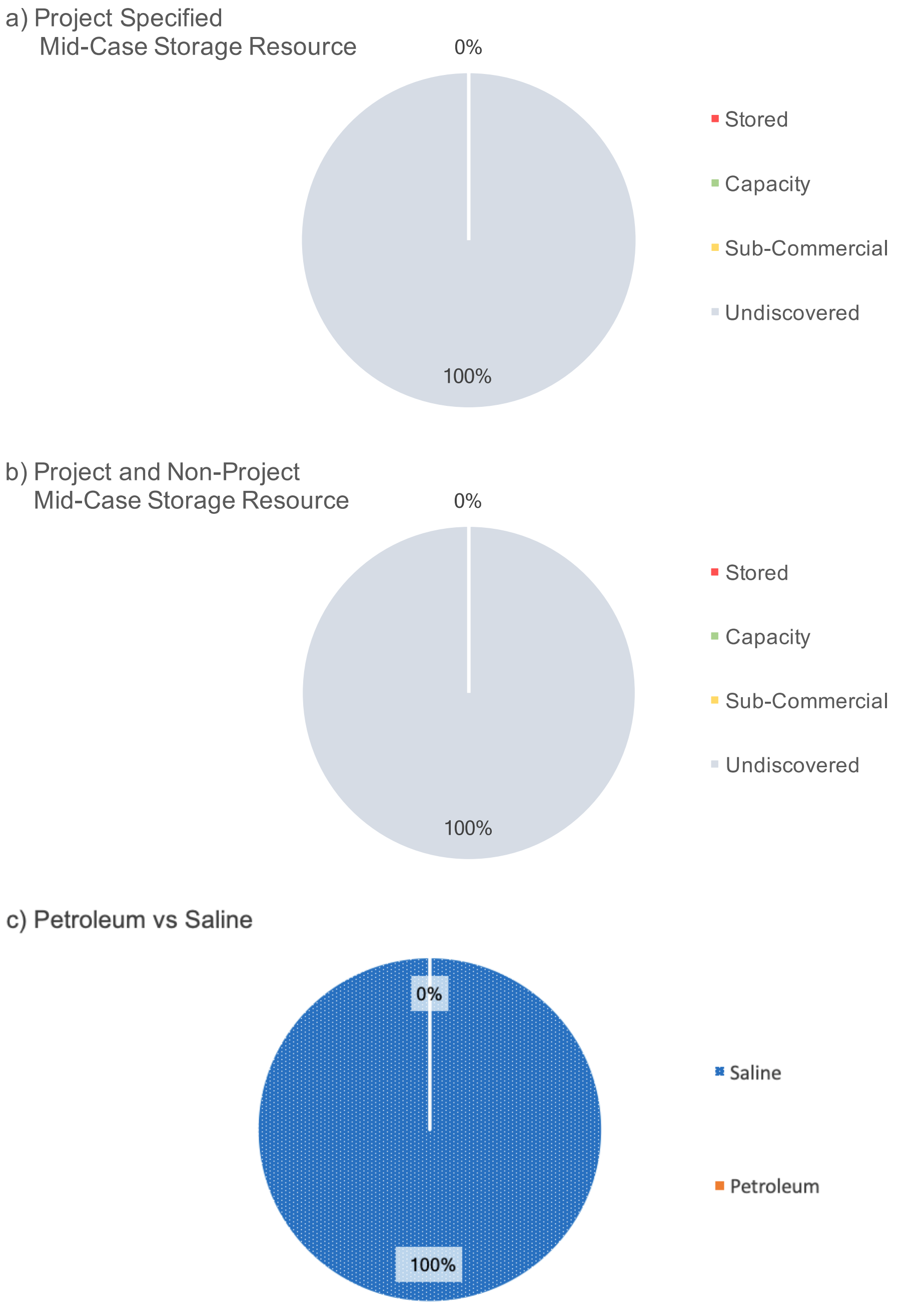


Figure 7-1: a) Spread of storage resource in Malaysia. sites (6) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Malaysia. sites across SRMS classifications; both project specified and not. c) Split of Malaysia storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

7.1.2 Resource Statement

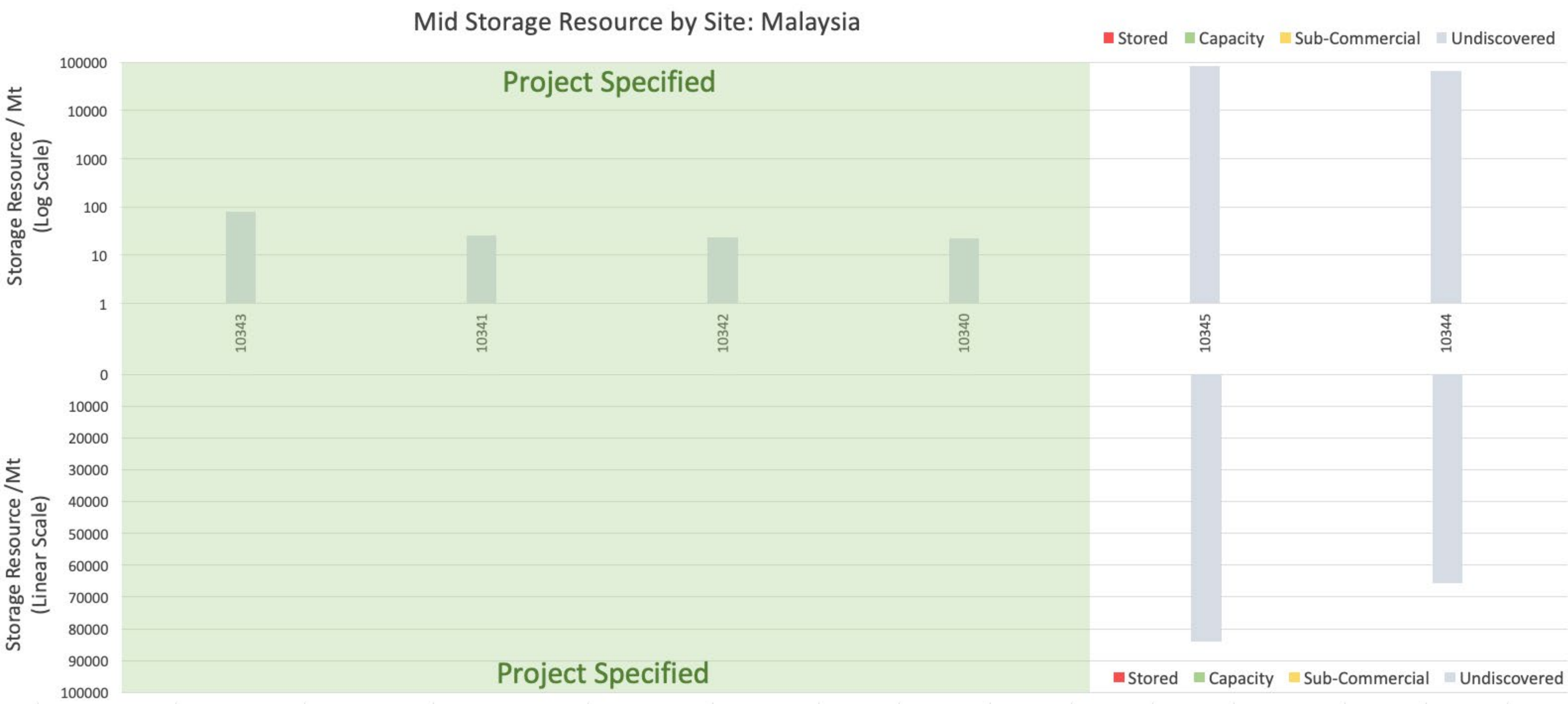


Figure 7-2: Storage resource summary for Malaysia compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

7.1.3 Evaluation History

The oldest evaluation of Malaysia's carbon storage potential was carried out by the Asia-Pacific Economic Cooperation in partnership with CO_2CRC. This assessment solely focused on storage of CO_2 co-produced with natural gas in south east Asia using a case study on CO_2 capture and storage from the cumulative gas stream of the undeveloped Tangga Barat cluster, Malay basin, although all estimates appear to have been generated using a simple volumetric methodology.

A regional study was undertaken by Junin and Hasbollah. [29], in which a dynamic spreadsheet (using geological and economic inputs) was used to assess 14 of Malaysia's sedimentary basins on their potential for carbon storage. This spreadsheet down selected to just two basins that are most suitable for CO_2 storage. The assessment criteria did not include proximity of the resource to large CO_2 emissions sources. The storage resource was calculated by the US-DOE [30]volumetric method for the two "high scoring" basins, these numbers are given as part of the 2020 Assessment. Junin and Hasbollah. [29] carried out this study in recognition of the fact that Malaysia's CO_2 emissions have been increasing by 1.9% per year since 1990, and if not acted on will continue to rise as Malaysia undergoes rapid economic growth.

Both of the above studies calculate storage resource using basic volumetric calculations. Based on lithology and depositional environment, all reservoirs presented will have a large variation in properties resulting in the resource estimates having low confidence.

7.1.4 Resource review

All storage resources assessed in this region are saline aquifers, however they can be subdivided into two different classes:

- Storage of CO_2 co-produced with natural gas: sites selected because of their close proximity to undeveloped natural gas fields with high percentage CO_2 content. These were classified as undiscovered as, although there are hydrocarbon exploration wells in the area, there is no direct mention of wells within the formation nor any indication of proximity to the storage resource site.

Basin wide storage resource – these have been classified as undiscovered as, although the basins have an active hydrocarbon exploration and production, there is no mention or location of any wells within the basins. Potential storage sites are mapped onto cross-sections, but these are not geographically-located.

7.1.5 Regulatory Framework

Malaysia has been evaluated under the 2018 GCCSI CCS readiness index [8]. However, there are no CCS-specific regulatory or legal frameworks that could directly assist a project in Malaysia. The readiness index gives Malaysia a high score for inherent interest; this means that based on the nation's economic dependence on fossil fuels, it would benefit from implementing CCS as a carbon emissions reduction strategy. However, the index shows that law and policy changes are needed to give more incentives for CCS project development.

An APEC (2010) study outlines a range of incentives that Malaysia has in place for environmental management, some of these may be relevant for CO_2 transport and storage practices. Incentives include: varying tax exemptions for companies providing energy conservation services; facilities to store, treat and dispose of toxic waste; or companies using environmental protection equipment. While CO_2 transport and storage practices do not currently qualify for these, it would be possible to make a case for their inclusion.

Malaysia has committed to reduce its emissions intensity by 40% by 2020 and 45% (relative to 2005 emissions) by 2030 as part of the Paris Agreement (UNFCCC, 2015). By 2011 they had already reduced emissions by 33% and, a recent announcement from the Malaysian state-owned energy company Petronas, states their aim of becoming a net zero emitter of greenhouse gases by 2050.

7.1.6 Issues for Assessment

The biggest issue with classifying all the Malaysia storage resources, was a lack of detail on data availability and location; no well numbers or locations were given despite some sites being in or near areas with significant ongoing petroleum exploration. This means that most of the resources have had their maturity downgraded.

Accuracy of resource estimates for most sites is limited by both the volumetric methodology used and the assumption of one set of reservoir properties for all estimates at all sites.

For all but one of the storage resources presented, there is only a single value for resource estimation. In cases where the resource estimation only reflects the volume of emissions over lifetime of project, the resource estimate has been recorded as the 'Low-Range' value. In all other cases the resource estimation has been recorded as the 'Mid-Range' value.

7.1.7 Future Updates

7.1.7.1 Future CSRC cycles

- Any updates on current potential storage sites should align with SRMS approach and methods to allow progress (maturation) up the classification system.
- Updates should be made if Petronas and other petroleum's companies release any well location data for the area's which contain storage resources in the Malay Basin and Greater Sarawak Basin. This would promote several storage resources from undiscovered to discovered.

8.0 South Korea

8.1.1 Summary

South Korea was assessed during Cycle 2. The CSRC has identified a CO_2 storage resource for South Korea as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.0	0.0
Capacity	0.0	0.0
Sub-Commercial	0.02	0.02
Undiscovered	203.3	0.0
Aggregated*	203.4	0.02

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 8-1 Storage resource classification summary for South Korea

- Storage resource potential is dominated by Undiscovered resource in saline aquifers in offshore basins. Only one gas field has been evaluated (Donghae-1).
- Potential storage resource has been identified in three offshore basins marginal to the Korean peninsula. Limited resource potential may exist in onshore basins, but these are generally too shallow and tight for large scale storage.
- As of February 2021, 203.4 Gt of potential resource has been reported from nine sites however all but one site is a basin-scale play and resource number should be flagged as carrying low confidence. No projects have been identified.
- The Ulleung Basin (East Sea) is considered to have the greatest commercial potential due to its location near the SE coast, however the Jeju Basin (northern East China Sea) holds greater resource potential. Data to support the resource statements is lacking.
- No current regulatory system exists with respect to CCS however South Korea has stated an ambitious Intended National Contribution (2015) and a Draft Korean CCS Act has been circulated.

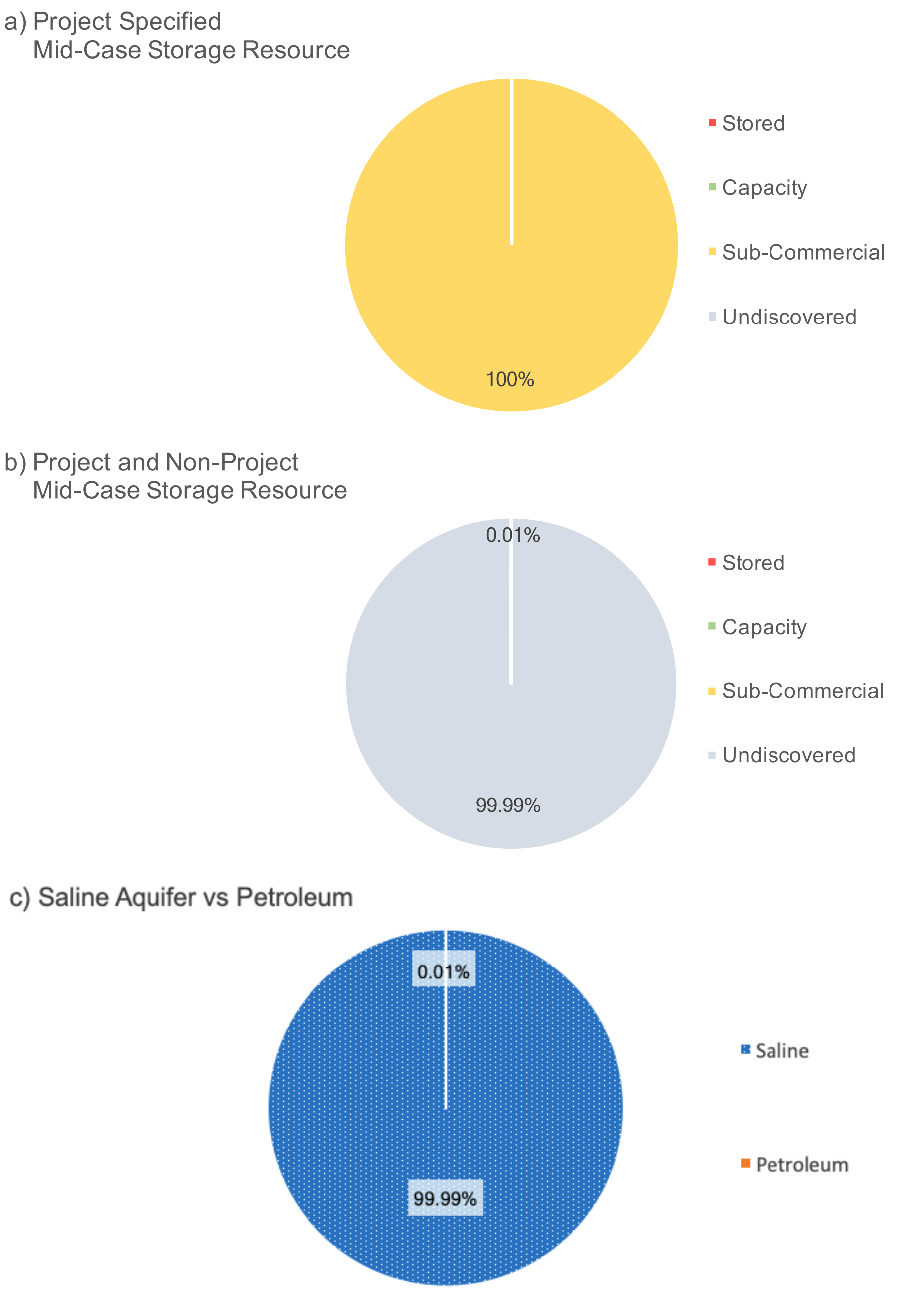


Figure 8-1: a) Spread of storage resource in South Korea. Sites (9) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all South Korea. sites across SRMS classifications; both project specified and not. c) Split of South Korea storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

8.1.2 Resource Statement

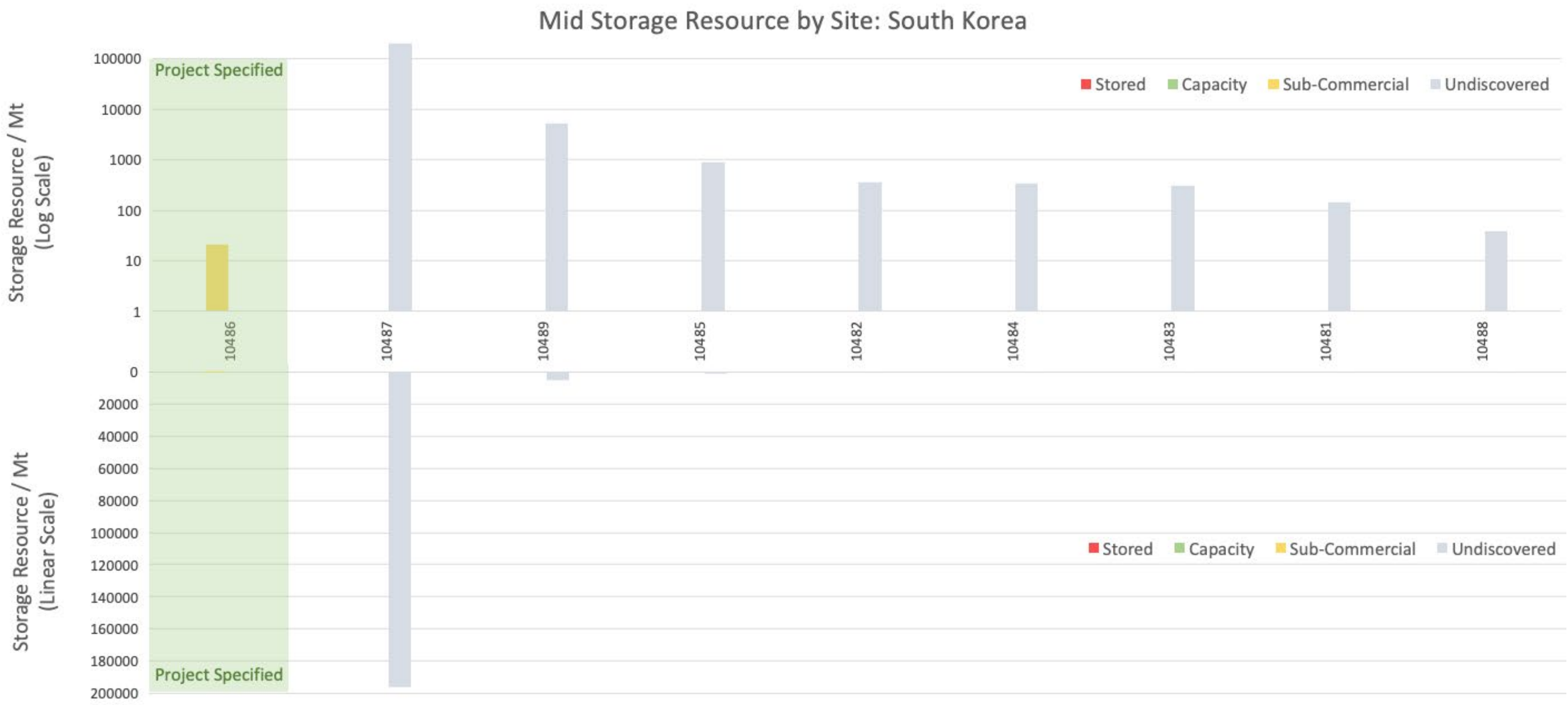


Figure 8-2: Storage resource summary for South Korea compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

8.1.3 Evaluation History

In general, the onshore geology of South Korea is considered unsuitable for commercial-scale CO_2 storage. According to Park et al. [31], Kim et al. ([32], Lee et al [33], and Huh and Yoo [34] the onshore basin geology is unfavourable for CO_2 injection and storage, being too shallow with low permeability. Saline aquifer storage is considered to hold the most potential due to the lack of a local hydrocarbon industry [32]. In addition, a 2017 5.4 magnitude earthquake in Pohang City (in the largest onshore basin) caused cessation of all fluid injection activities (both CO_2 and geothermal). Post-event analysis suggests the earthquake was induced by water-injection in an enhanced geothermal system [35].

Studies have been undertaken in both the onshore and offshore areas in South Korea. Of the three offshore basins (the Ulleung basin in the East Sea, the Jeju basin in the East China Sea to the south of the peninsula, and the Kunsan basin in the Yellow Sea to the west). The Ulleung basin has been considered the most feasible due to the presence of gas-bearing structures [36] [35] and closer proximity to major emissions sources. Further developments made be possible as KNOC and Woodside began exploration in the Ulleung Basin in 2019 and new drilling contract (awarded February 2021) for the area may lead to further data availability. The data availability in the Yellow Sea (6 wells, plus 2D and limited 3D) and the Jeju Basin (14 wells plus 2D and some 3D surveys) is more restricted.

The calculation methods used to assess resource potential are essentially volumetric methodologies using the DOE/NETL [37] approach. No projects have been identified which meet the Global catalogue threshold of 10 Mt for inclusion.

8.1.4 Resource Review

The current classification of potential storage resource in South Korea is significantly limited due to the lack of robust data sets for evaluating the saline aquifers. The approach taken here is to adopt a minimum maturity level approach to classification; resources can progress to more mature classes when there is both evidence and quantification available. The stated resource for South Korea is considered an overestimation as it represents a theoretical value based on limited data.

All resource entries (both saline aquifer and the single gas field) are classified as 'Inaccessible' at this stage due the lack of a regulatory system for CCS and any knowledge on gas field accessibility dates).

8.1.4.1 Major Projects

No major storage projects have been announced by South Korea. The Korea 2020 project was a major national plan controlling technology development, R & D, and promotion of CCS facilities. Although the projects identified are heavily focused on carbon capture the project did carry the goal of selecting a storage site suitable for the injection of 10,000 t CO_2. Two potential sites are discussed in the literature, the Yeong-Il Bay site in the offshore Pohang Basin and the Noeseongsan block in the onshore Janggi Basin. Although start-up of injection was due to be in 2016-2017, no mention of these pilot projects was found in the public literature or on the Korea 2020 website. Simulation of injection at the Yeong-Il Bay site indicated a maximum injection volume of between 40,000 t [38] and <1 Mt [39] before maximum allowable pressures were reached.

8.1.4.2 Depleted Oil & Gas Fields

The Ulleung Basin (East Sea) contains the only identified gas-bearing structures and the only active hydrocarbon field in South Korea. The Donghae-1 gas field(Gorae structure) and the attached aquifer has been evaluated for a range of injection scenarios, with post-depletion CO_2 injection with brine extraction giving the most optimistic resource (24.3 Mt; [36]). Additional gas-bearing structures in the Ulleung Basin (e.g., Dolgorae) may hold potential but no evaluations are available to this cycle of assessment.

8.1.4.3 Saline Aquifers

The storage resource in South Korea is dominated by the basin-scale saline aquifer resource estimates. Few publications provide sufficient back-up detail to support the published resource estimates, for example, the Taebaek Basin (onshore) has a published resource estimate of 3 Mt (sandstones; [40]) but presentations by the KCCSA [41] quote 180 Mt. In the absence of supporting information for this estimate, the Taebaek Basin resource is not included in the Cycle 2 Assessment. The greatest onshore resource potential is held in the Gyeongsang (Kyoungsang) Basin in which up to 1 Gt resource [42] was calculated in sandstones units from 3 separate locations. The highest potential, 535 Mt, was identified in channel sandstones from these locations. An alternative estimate of 680 Mt for the basin are given by KCCSA [41] but with no supporting data. In the absence of more detailed analysis, these sites may warrant further evaluation. In the south east of the peninsula, the onshore Janggi Basin was evaluated as a potential pilot project location with emphasis on the Janggi Conglomerate and the clastic Seondongri Formation, both of which show significant theoretical resource estimates (142 Mt and 26 Mt respectively [38]; [43] but probabilistic estimates of the effective resource (fluid phase) do not meet the Catalogue threshold (1 Mt and 0.2 Mt respectively).

Three offshore basins have undergone evaluation of their storage resource. The most advanced is the Ulleung Basin where subsurface data (seismic and well) is available. The Jeju Basin to the south has been evaluated but used a simplistic approach dividing the study area into a layer model (cross-cutting geological/lithological boundaries). The estimated resource range of 24 – 690 Gt (average: 196 Gt) is considered a significant overestimation. To the west, the Gunsan (Kunsan) Basin was evaluated by MEST (2008; in Korean) with a reported 254 Mt resource, although this has also been linked to EOR [32] and as such is not currently included in the Catalogue.

8.1.5 Regulatory Framework

Following an initial GHG reduction goal of 30% (243 Mt) of 2020 BAU emission (813 Mt), with 2Mt of the total to be achieved through CCS, the South Korean government announced an Intended Nationally Determined Contribution (INDC) of a reduction of 37% of GHG emissions compared to 2030 BAU. CCS is seen as a key technology to achieve low carbon growth [44] but currently has no CCS-specific regulatory system, although a Draft Korean CCS Act has been circulated. As a result, all resource entries in the Global Catalogue are currently sitting in the Inaccessible category. This may be changed as soon as any legal and regulatory system is adopted. South Korea did test an emissions trading scheme (started in 2010), with the goal of the scheme taking effect in 2015.

8.1.6 Issues for the Assessment

While South Korea has been proactive at setting up national plans (e.g., Korea 2020) for R&D and technology development, most of the focus to date has been capture technology. The proposed 10,000t storage pilot has not been reported on in the literature although this may relate to cessation of activities following the 2017 Pohang earthquake.

Current published evaluations of storage resource potential are high level, basin scale estimates with no projects (except for the Yeong-Il Bay pilot study which is <1Mt) available for inclusion in the Global Catalogue.

8.1.7 Future Updates

8.1.7.1 Future CSRC cycles

There is limited information on future carbon storage development in South Korea, however it is anticipated that this may change if the country looks to CCS to help meet its current INDC. Future assessment cycles should check for developments.

9.0 Thailand

9.1.1 Summary

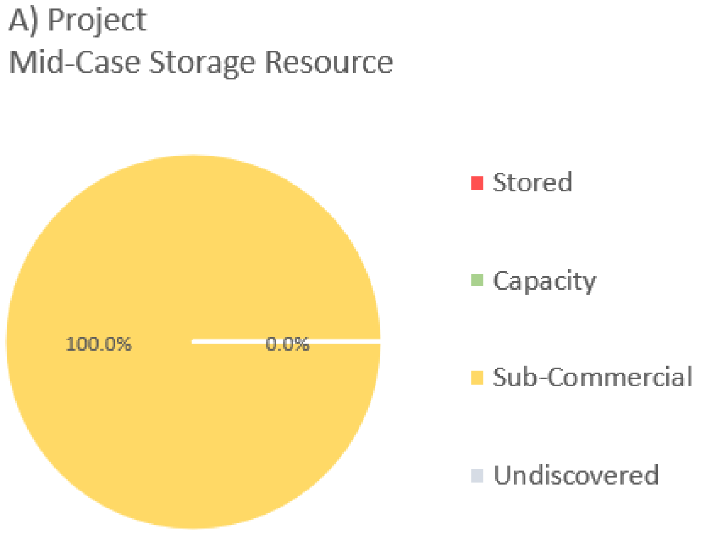
Thailand was assessed during Cycle 3. The CSRC has identified a CO_2 storage resource for Thailand as follows:

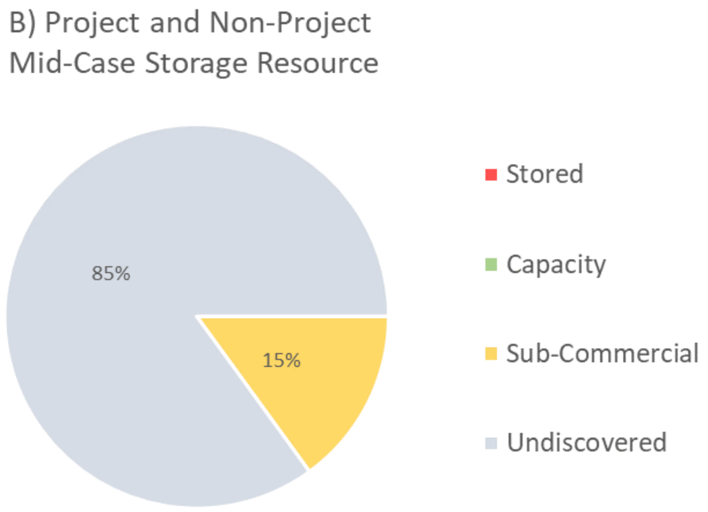
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	1.571	0.011
Undiscovered	8.9	0.070
Aggregated*	10.471	0.011

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 9-1: Storage resource classification summary for Thailand.

- There are currently 39 sites at both local and regional scale, located across a minimum of 10 basins both onshore and offshore
- One of these evaluations has a project defined
- Only two sites in the country are saline aquifers, the remaining 37 are all petroleum
- There are no active CCS projects in Thailand
- The Thai Government have not yet development a CCS specific regulatory framework





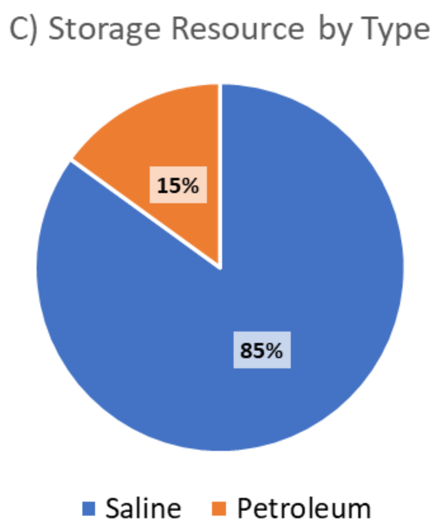


Figure 9-1: a) Spread of storage resource in Thailand. Sites (39) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Thailand. sites across SRMS classifications; both project specified and not. c) Split of Thailand storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

9.1.2 Resource Statement

Figure 9-2: Storage resource summary for Thailand compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

9.1.3 Evaluation History

A number of storage resource evaluation studies have been carried out on potential opportunities in Thailand. Most of these focus on offshore depleted hydrocarbon fields:

- The earliest published evaluation of Thailand's carbon storage potential was carried out by the Asia-Pacific Economic Cooperation in partnership with CO_2CRC [3]. This evaluation is solely focused on storage of CO_2 co-produced with natural gas in southeast Asia. Only a single site with 70Mt resource is presented in this publication for Thailand. For all resources presented, a simple simulation was conducted to determine the maximum rate of CO_2 that can be injected over the injection period without the pressure in the reservoir exceeding its fracture pressure.
- A country-wide storage resource screening study for Thailand was carried out by the Asian Development Bank in 2013 [15]. Here, qualifying criteria were used to screen all sedimentary basins in the country for both saline aquifer and petroleum resource. This study gives resource estimates for individual depleted oil and gas fields and a cumulative resource for all saline aquifers deeper than 1000m in the country. Almost 70% of the gas fields studied are located in the Pattani Basin with the remainder in the Greater Thai, Malay, Greater Chao Phraya, Phitsanulok, and Greater Khorat basins. The screening criteria used to select and score each of the potential petroleum storage sites included the following attributes: Capacity, Injection rate, depth, seal integrity, and absence of active faulting. Site scores also evaluated the number of production/ injection and abandoned wells and economic criteria (e.g., existing infrastructure, willingness of operator etc.). Replacement volume calculations were used to calculate depleted field storage resources and were based on cumulative production data for oil, gas and water and reserve estimates. Saline aquifer resource was estimated using rough pore volumes of all formations.
- Choomkong 2017 [45] presents an updated evaluation of Thailand's country wide depleted petroleum resource. The results are presented as cumulative values per basin and sub-basin. This study does not use any screening criteria therefore each basin resource will include some resource that is not commercially viable. To calculate storage resources, oil and gas STP values were converted to equivalent CO_2 tonnage stored using a standard conversion for all fields included. This assumes constant pressure and temperature gradients as well as permeability throughout. This paper also considers CO_2 sources, as the storage resource results are presented next to their closest emitters. This study was in response to Thailand's Alternative Energy Development Plan (2015-2036) which was developed in response to increased electricity demand that is expected in order to keep pace with the economic growth of the ASEAN Economic Community. This study evaluates depleted field storage within the same basins as ADB 2013 but applies no screening criteria and does not give resource values for individual fields, therefore it has been decided to include the depleted field resources from ADB 2013 in the CSRC instead of those from this study).
- Maneeintr 2017 [46] presents a dynamic simulation of CO_2 injection for the Fang Oilfield – Thailand's northern most resource. Reservoir information was derived from the Defense Energy Department, Northern Petroleum Development Centre, and CMG's GEM software package was used to simulate CO_2 injection into this reservoir. The three Injection rates simulated were based on CO_2 streams coming from

the Mae Moh Power plant. These rates were: 1000, 2000 and 4000 tons/day over periods of 35, 17, and 9 years.

- Choomkong 2020 [47] is the most recent study evaluated in the CSRC and focuses on the Bua-Ban oilfield in the Songkhla basin, which sits close to shore near the border with Malaysia. A block geo-model was created for two intervals within this AOI, the lower Oligocene and the lower Miocene. The lower Miocene interval was only simulated with total injected CO_2 of 2.71Mt so has not been included in the CSRC. The Simulation was run on Eclipse 2017, Injection rates and total volume in the model were programmed to match CO_2 streams from the Chana powerplant in the period from 2015 to 2017. The static model was created on Petrel using data from 164 wells in the area and a local geophysical survey.
- Two depleted gas field studies, located in the Malay basin were also reviewed but did not meet the CSRC 10 Mt storage resource threshold. Rawangphai 2018 [48] reported a resource of maximum 2Mt, while Maneeintr 2018 [49] reported a total resource of 6Mt for a different field. Both studies simulated injection using GEM software package.

9.1.4 Resource Review

9.1.4.1 Introduction

The majority of resource sits in the petroleum category, with most located offshore in gulf of Thailand Basins. Only two studies are listed for saline aquifer resource, and these have a significant lack of accompanying data.

9.1.4.2 Pilot Projects

No pilot projects have been announced by Thailand.

9.1.4.3 Depleted Oil & Gas Fields

The majority of reported storage sites sit within depleted oil and gas fields. The offshore Pattani and Malay basins contain 75% of these sites but all have limited geographic and geological data for each individual field. Onshore depleted petroleum resources are minimal. The potential 16 Mt resource in the Fang Oil field near the border with Myanmar is situated near the large stationary emissions of the Mae Moh power plant and benefits from a more detailed study including estimates of dynamic capacity and injectivity. An in-depth study to evaluate potential storage in the Songkhla basin, has identified a 10.8Mt storage site located close to the onshore stationary emissions of Songkhla province. Other onshore resources that sit close to emissions hubs include the Phu Horm and Nam Phong fields (Greater Khorat basin), and the Kamphaeng Saen and Suphanburi fields (Greater Chao Phraya basin), as well as the cumulative depleted petroleum resource of the Phitsanulok basin in NW Thailand.

9.1.4.4 Saline Aquifers

Storage potential in saline aquifers is currently limited in Thailand. A study by Asian Development Bank [15] reviewed aquifer resource potential in 94 basins & sub-basins across the country however only 10 basins were considered to be sufficiently well understood to generate a storage resource estimate for formations sitting below a 1000m depth cut-off. The 84 basins that did not make the cut lacked sufficient data to make the resource calculation.

A saline aquifer was evaluated as a potential storage target for CO_2 in produced gas from a high CO_2 field in the Pattani Basin. A simple injection simulation in to the aquifer (located approximately 20 km from the field) injected 70 Mt over a 20-year period without exceeding the formations fracture pressure.

9.1.5 Regulatory Framework

As of 2017, the baseline annual emissions used for the country was 300Mt/ year, but these emissions rates have been dramatically increasing in line with economic growth. Thailand has committed, under UNFCC 2015, to reduce emissions by 20-25% below BAU levels by 2030. This means that the country will need to cut emissions by 110-140 Mt-CO_2e within the next 9 years to meet this target. The Thai Government has developed several action plans to achieve this goal. These plans include: the National Economic and Social Development Plan, the Climate Change Master Plan (2015-2050), the Power Development plan (2015-2036), the Alternative Energy Development Plan (2015-2036), amongst others. The Power Development plan focuses on reduction of CO_2 emissions from the power sector and may be able to offer incentives for CCS in Thailand. Currently however, the country has no CCS specific regulatory system [8], therefore all resource entries in the CSRC (Cycle 3) sit in the Inaccessible category, however, a presentation at ASEAN Clean Energy Forum 2020 by the Ministry of Energy states that the "definition of principles for Thailand's CCS regulations within international context" has been partially completed and the country is on route to creating CCS specific regulations.

9.1.6 Issues for the Assessment

The only storage atlas for Thailand is the Asian Development Bank (ADB) 2013 report [15]. This presents the majority of Thailand's storage resource estimate in the CSRC to date but, due to limited accompanying data, the overall maturity of the resource assessment is low. Although the ADB study report gives individual storage resource estimates for all gas fields greater than 10Mt, these figures cannot be linked to geographic location as the map does not display field names. If this location data existed, it would help avoid the likely double accounting issues between ADB 2013 and Choomkong 2017 [45].

The only project site entry in the CSRC is the Bua-Ban field [47]; this would also be assessed at a higher SRMS maturity class if Thailand developed a CCS regulatory framework. The standout issue with this project entry, however, is clarity on existing *versus* virtual well data utilised for the static modelling effort. Although 164 well are displayed on the block model, it is unclear if some of these wells are virtual wells based on offset wells in the greater Songkhla basin, or if all these wells physically exist within the model bounds. For the purpose of this assessment, however, the AOI has sufficient wells to make the area 100% discovered under the SRMS.

9.1.7 Future Updates

Any evaluations that further interrogate the countries saline aquifer resource would be valuable in building a more complete picture of the potential storage resource in Thailand. Indeed, future studies should focus on assessing aquifers that are linked to the many depleted gas fields available for storage, such as those in the Pattani, Greater Chao Phraya, and Greater Khorat basins. These areas will have a large amount of geological data accessible from the Department of Mineral Fuels.

Also, the CSRC would benefit from studies that present more robust data (both geographic and subsurface) for depleted petroleum fields in the Pattani, Greater Chao Phraya and Greater Khorat basins.

10.0 Vietnam

10.1.1 Summary

Vietnam was assessed during Cycle 3. The CSRC has identified a CO_2 storage resource for Vietnam as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	0.924	0.00
Undiscovered	20.826	0.076
Aggregated*	21.750	0.076

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 10-1: Storage resource classification summary for Vietnam.

- There are 28 sites at both local and regional scale, located across a minimum of 7 basins both onshore and offshore.
- Three of these evaluations have a project defined.
- 9 sites in the country are saline aquifers with the remaining 19 sites sitting in the Petroleum category.
- There are no active CCS projects in Vietnam.
- The Vietnamese Government have not yet development a CCS specific regulatory framework.

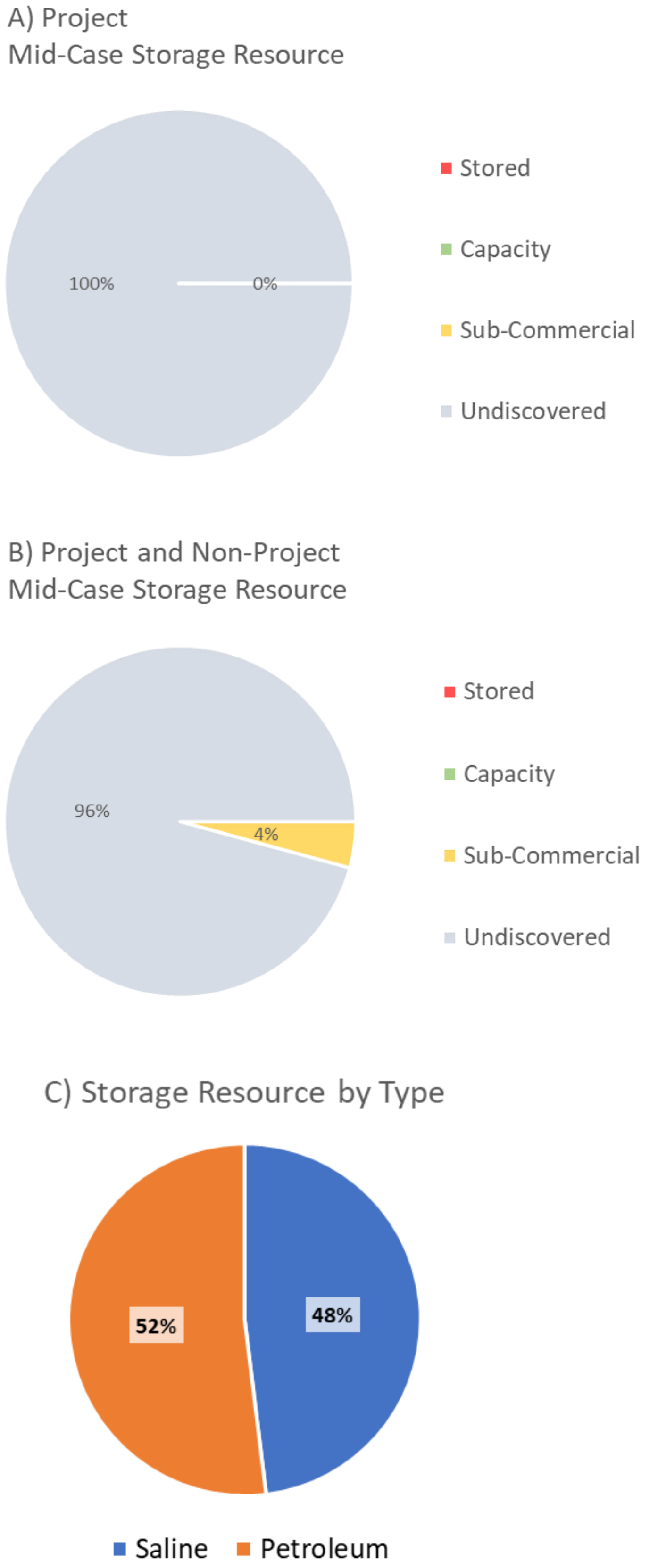


Figure 10-1: a) Spread of storage resource in Vietnam. Sites (24) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Vietnam. sites across SRMS classifications; both project specified and not. c) Split of Vietnam storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

10.1.2 Resource Statement

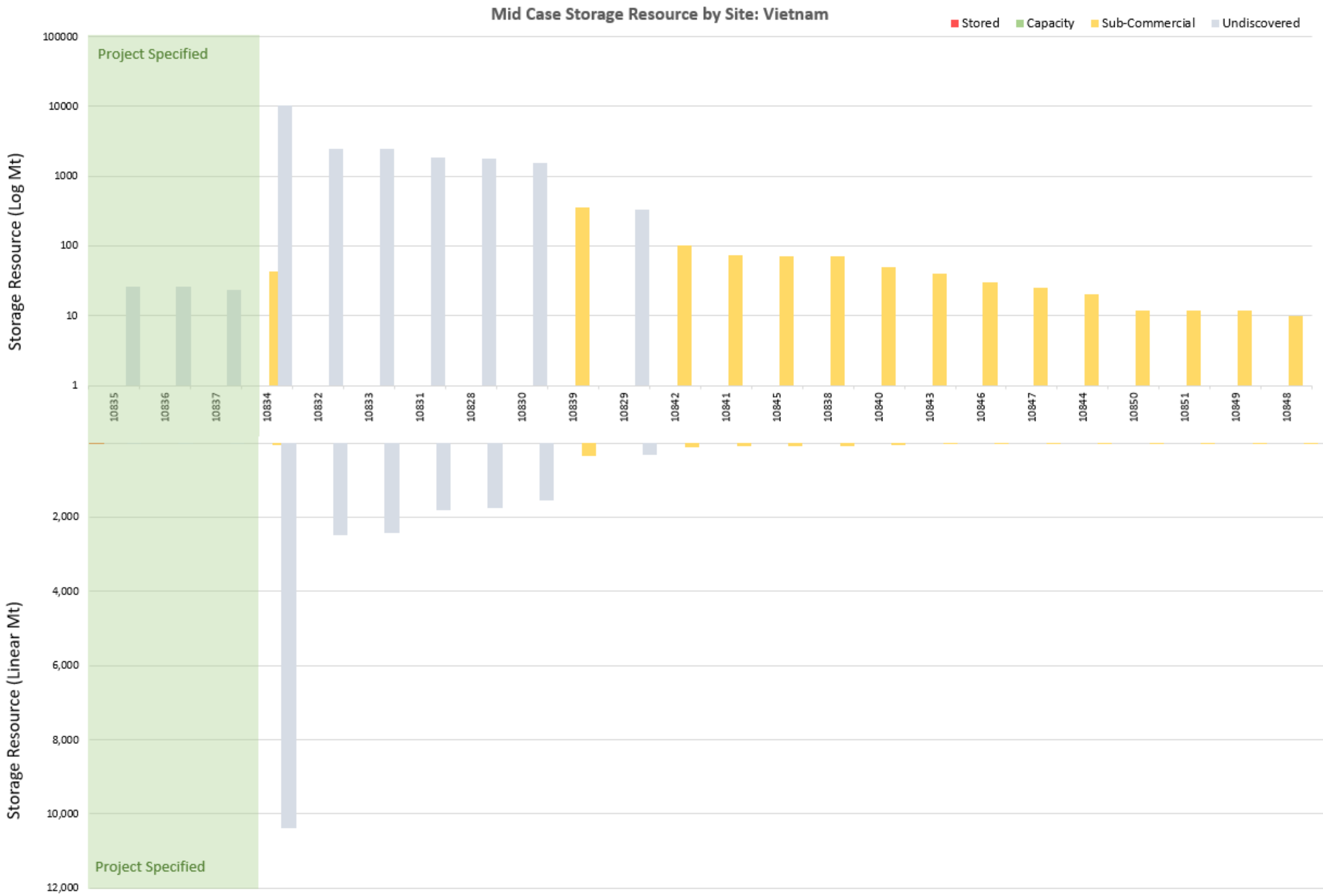


Figure 10-2: Storage resource summary for Vietnam compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

10.1.3 Evaluation History

The published resources for Vietnam describe three main evaluations over the past decade:

The oldest regional evaluation of Vietnam's carbon storage potential was carried out by the Asia-Pacific Economic Cooperation in partnership with CO_2CRC (2010) [3]. This assessment solely focused on storage of CO_2 co-produced with natural gas in south-east Asia but data for Vietnam is limited to formation data, development plans and storage estimates noted briefly in the appendix tables. For all resources presented, a simple simulation was conducted to determine the maximum rate of CO_2 that can be injected over the injection period without the pressure in the reservoir exceeding its fracture pressure.

The main, published regional study for storage in Vietnam was produced by the Asian Development Bank (2013) [15], it uses qualification criteria to screen for depleted petroleum resource and also gives six basin play resource estimates. This screening limited petroleum resource to fields in the Cuu Long, Panjang and Nam Con Son Basins. The best storage targets are in the Cuu Long basin – this has been verified by a suitability score, calculated for each field. Besides storage resources and suitability score however, data quality is quite poor for these fields, i.e. there is no formation data, and it is not possible to locate specific fields on the map figure. Storage estimates were calculated by replacement volume. As well as these gas field estimates, the report also gives storage resources for six Vietnamese basin plays (only considering storage by structural/ stratigraphic trapping at depths greater than 1000m). The estimation approach appears to be volumetric, although no methodology was given.

Vo Thanh, 2019 [50] present a study that is solely focused on CO_2 storage combined with CO_2 EOR in the fractured basement reservoir of the Nam Vang depleted field in the Cuu Long Basin. Fractured basement plays are considered unconventional in the petroleum industry, and have rarely been considered for carbon storage. The main purpose of the study was to create an efficient workflow for generating accurate static geological models of fractured basement reservoirs that can be used to calculate CO_2 storage resources. Here, faulting data from seismic was combined with porosity data from well logs using artificial neural network technology, these were then integrated into a static model using the Co-Kriging tool. The accuracy of this model was validated by performing drill stem test matching. The resource was calculated by volumetric method (E ranged 0.1 – 0.9) using this static model. This is the first resource within fractured basement reservoir to be included in the CSRC.

10.1.4 Resource Review

10.1.4.1 Pilot Projects

Vietnam has no known pilot projects.

10.1.4.2 Depleted Oil & Gas Fields

Depleted fields represent the only discovered resource in Vietnam. They range in size from 355Mt to just 10Mt and are all located within the Cuu Long and Nam Con Son Basins, offshore southern Vietnam. The Asian Development Bank (2013) [15] gives resource estimates for twelve depleted fields in the Cuu Long basin and two for the Nam Con Son basin. These estimates are not accompanied by any reservoir data or exact locations within the basin; the fields presented were screened using desirable qualifying criteria e.g., capacity, injection rate and confinement. The selected fields are also accompanied by a suitability score which includes the above criteria plus number of existing active and abandoned wells, contamination risks for other resources, and an economics section including existing infrastructure, monitoring potential, availability, and willingness of operator. The Cuu Long basin is located closest to the large stationary emissions of southern Vietnam. Field CL16 in the Cuu Long has the largest discovered resource (355Mt) in Vietnam and carries the highest suitability score in Asia Development Bank, 2013 report [15].

The Nam Vang field (Cuu Long basin) is estimated to have 43.2Mt storage potential.

10.1.4.3 Saline Aquifers

The saline aquifer resources in Vietnam fall into two categories, large basin play aquifers and small aquifers that are near high CO_2 fields in the region. The large-scale basin play resources are given for all but one of the sedimentary basins, overall, they represent over 90% of the country's total resource [15]. However, these resources are not accompanied by any additional data e.g., storage efficiency factors or reservoir and wells data.

The smaller scale saline aquifers represent less than 1% of the country's aquifer resource, given by CO_2CRC (2010) [3]. All three resources are considered projects because they include development plans and simple reservoir simulations (injection without exceeding fracture pressure), as well as in-depth formation data. But as these resources were chosen specifically for their proximity to offshore high CO_2 fields, their location may not be optimized for storage from large onshore emitters.

10.1.5 Regulatory Framework

Despite being South-East Asia’s 3rd largest oil and gas producer [51], Vietnam has not developed any laws specific to CCS deployment. To progress any CCS activities in Vietnam a legal and regulatory framework is required.

Vietnams latest emissions reduction plan [52] submitted to the UN, commits the country to cut emissions by 9% based on business-as-usual projections, using a 2014 baseline. However, this would still see emissions grow by 844Mt during this time period due to new infrastructure development, e.g. Vietnams large cement sector is the third largest producer in the world.

Due to this lack of regulatory framework for CCS, all storage resources for Vietnam in the CSRC are classified as inaccessible under the SRMS.

The Global CCS Institute’s CCS Readiness Index (2018) [8] ranks Vietnam just above 70 percent for inherent interest meaning that it has a high fossil fuel dependency and therefore is likely to need CCS projects to meet future climate goals, additionally CCS is the only way to decarbonize the country’s mammoth cement industry. Currently it appears that Vietnam is more focused on CO_2 EOR projects over storage projects due to their financial incentives (e.g., storage combined with EOR in the Nam Vang Field, Cuu Long basin).

10.1.6 Issues for the Assessment

The largest issue encountered by the Cycle 3 assessment is the lack of data that accompanies the seven basin play resources (90% of the country's total resource). The only data provided is the resource estimate and location; any additional information on storage efficiency factors used, and the relative porosities and depositional environments would increase the credibility of these resources.

More specific locations and reservoir data for the depleted petroleum fields from the Asia Development Bank 2013 [15] report would dramatically increase the credibility of these sites.

10.1.7 Future Updates

Future assessments should include any new or updated information on the storage resources in Vietnam. The issues discussed above mean that the overall resource classification is likely to be assessed at a lower maturity than necessary.

In terms of additional resources for future evaluations, Vietnam would benefit from some detailed appraisals on larger scale aquifers as currently the only detailed aquifer studies have ~25Mt storage potential in each site. Also, any studies of both petroleum and aquifer resources for Vietnams northern basins would improve the distribution of storage resource throughout the country – including giving storage options for emitters associated with Vietnam's capital Hanoi.

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