ASEAN CCS Deployment Framework and Roadmap

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Foreword

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The economies of Southeast Asia's are steadily developing, and fossil fuels are expected to continue dominating the region's energy mix for some time yet. The 8th ASEAN Energy Outlook (AEO8) projects that by 2050, fossil fuels will account for 76% of ASEAN's total primary energy supply. Consequently, ASEAN's energy-related greenhouse gas emissions will amount to 2,215 million metric tons of CO_2 equivalent in 2020. Aligning with the global momentum in emissions reduction efforts, the region announced the ASEAN Carbon Neutrality Strategy in 2023 which places energy security high on the national agenda.

While CCS technologies can capture and store the carbon emissions resulting from ASEAN's heavy reliance on fossil fuels, the region faces several challenges in deploying them. Hence, the CCS technologies have not yet been widely deployed in the region. The formulation of a regional CCS Development Framework and Roadmap has long been mandated by the ASEAN Ministers as part of the energy annual priorities of the ASEAN Chairmanships, from Cambodia in 2022, Indonesia in 2023 and Lao PDR in 2024. In this regard, on behalf of the ASEAN Centre for Energy, I am pleased to announce the release of the ***ASEAN CCS Deployment Framework and Roadmap.***

This Report aims to assess the status of CCS policy, legal and regulatory framework, and storage in ASEAN, and then propose a Roadmap. Based on the findings of our research, we have five key recommendations to help pave the way forward for a robust CCS deployment in ASEAN to be implemented in the short-, medium- and long-term periods. These are: enhancing the economic viability of CCS development, shortening the long lead times and accelerating the CCS domestic deployment, managing project complexity and derisking CCS deployment, narrowing the technology innovation gaps, and facilitating CCS hubs and international transboundary CO_2 movement.

I would like to extend my gratitude to all of the ASEAN Forum on Coal (AFOC) and ASEAN Council on Petroleum (ASCOPE) Focal Points and other government agencies and experts, as well as the Global CCS Institute (GCCSI) through the Southeast Asia CCS Accelerator (SEACA) Programme, for their strong support and guidance enabling the completion of this Report.

It is my hope that the findings and recommendations will provide valuable insights and references for ASEAN policy makers, project developers and other CCS stakeholders and experts to collectively accelerate the deployment of CCS in the region. The ASEAN Centre for Energy's regional energy blueprint document, the ASEAN Plan of Action for Energy Cooperation (APAEC) aims for the region to accelerate its energy transition and strengthen its energy resilience through greater innovation and cooperation, including through CCS technologies.

Acknowledgements

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Overall guidance and supervision were provided by Dr Nuki Agya Utama, Former Executive Director, Mr Beni Suryadi, Acting Executive Director, and Mr Christopher Zamora, Senior Manager of ASEAN Plan of Action for Energy Cooperation (APAEC) of ACE.

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Executive Summary

Almost unimaginable amounts of energy are required to fuel the rapid economic growth currently taking place in the Association of Southeast Asia Nations (ASEAN). Projected to be the fifth largest economy in the world by 2050, ASEAN's total primary energy supply is projected to increase to 1,823 Mtoe by 2050 from 698 Mtoe in 2022.

Fossil fuels have dominated the region's energy mix, accounting for about 82% in 2022. The share of fossil fuels is expected to reach 76% by 2050, even assuming the most aggressive renewable energy and energy efficiency policies and measures. Oil is the largest component, followed by natural gas and coal.

Consequently, **ASEAN's energy-related greenhouse gas emissions have been high, amounting to 2,215 million metric tons of CO_2 equivalent in 2020**, equivalent to 4.3% of the world's total emissions. To date, nine out of ten ASEAN Member States (AMS) have recently updated their Nationally Determined Contributions (NDCs) in adherence to the Paris Agreement. Regionally, ASEAN established its Carbon Neutrality Strategy in 2023, charting strategies to be conducted up to 2050.

However, given that the AMS are mostly developing economies, the balance between energy transition and energy security must be taken into particular consideration. Due to its abundance and affordability, coal has been fundamental in supplying electricity. An abrupt energy transition from fossil fuels to renewable forms of energy could jeopardise the region's energy security, especially given the intermittency issues of renewable energy. Moreover, ASEAN's coal power plants are relatively young with still many years of economic life ahead. Early retirement of these plants would mean buying out future coal generation based on their contracts with power utility companies that would amount to billions of US dollars. At the same time, governments would need billions of dollars to invest in grid upgrades and battery storage for the variable renewable energy. The heavy industries such as cement, steel and chemical production are extremely energy intensive and hard-to-abate, emitting over 17% of the CO_2 emissions.

As energy consumption and CO_2 emissions continue to rise, mitigation measures must be applied that do not compromise energy security. This is where carbon capture and storage (CCS) comes in. ASEAN has also acknowledged the crucial role of CCS and has embedded CCS policies into its regional commitment through the 41st ASEAN Ministers on Energy Meeting (AMEM), ASEAN Carbon Neutrality Strategy 2023 and ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021 – 2025. CCS has been a priority of the ASEAN Chairmanship each year since 2022.

Despite the strong support and significant potential of CCS (particularly in Indonesia, Malaysia, Thailand and Viet Nam), the deployment of CCS in the region is stagnating due to challenges surrounding its economic viability, long lead times, project complexity and innovation gaps.

Therefore, to accelerate the deployment of CCS, this report aims first to assess the current status of three key CCS pillars in ASEAN: **(i) policy; (ii) legal and regulatory framework; and (iii) storage**. The assessments were based on discussions conducted at the Southeast Asia CCS Accelerator (SEACA) 2023 workshops organised by the Global CCS Institute in collaboration with ACE, desk research, online questionnaires, and closed-door focus group discussions with representatives from all of the AMS. **The assessment of the three pillars is the basis of the Framework section of the Report. From the Framework, a CCS Deployment Roadmap is developed, along with policy recommendations.**

Under the **policy pillar (Chapter 3),** it is apparent that the **AMS exhibit varying levels of readiness and commitment across the policies enabling CCS deployment**. Indonesia and Malaysia (Sarawak) lead in implementing specific **legal framework** and policies to support CCS projects, which include financial measures such as grants/tax incentives, monetisation and carbon pricing, while Thailand and Viet Nam are still focusing on research and development. In terms of **cost reduction measures**, the AMS are employing a mix of grants and tax credits to alleviate the capital-intensive nature of CCS deployment. Indonesia and Malaysia for example, have opted for revenue **support** through a regulated asset base model to support CCS projects in infrastructure-heavy sectors. The **involvement of state-owned enterprises** (SOEs) and therefore the **regulation of industrial activities** are also crucial to reduce the costs of CCS by potentially mitigating the investment risks. Finally, **strategic signalling,** the amount of CCS policy integration into national strategies, varies among the AMS, epitomised by the amount of CCS integration into the national strategies. The way forward for the policy pillar involves enhanced **policy coordination among stakeholders, as well as increased financial incentives** to accelerate the adoption of the CCS technologies.

With regards to the **legal and regulatory framework pillar (Chapter 4), Indonesia and Malaysia (Sarawak) are the front runners among the AMS,** with the former having established national legal frameworks specifically addressing CCS activities in the upstream oil and gas sector. Examples are the **MEMR Regulation No. 2/2023** and **Presidential Regulation No. 14/2024**. The latter established the **2022 Land Code (Carbon Storage) Rules**, which regulate the use of land offshore and onshore for the development of carbon storage sites. In both countries, the regulation extends to **outlining the ownership of CO_2 and ownership responsibilities**, measures to ensure **safe and secure storage** throughout the facilities' lifecycles, the **long-term liabilities associated with CO_2 storage sites**, and the obligatory **environmental reviews and permitting.** Indonesia even goes further by including a framework for **transboundary CO_2 transport**, paving the way for an **ASEAN**

CCS hub. As the formulation of complex regulations for CCS involves effective coordination among multiple stakeholders, a mapping of the tasks that the stakeholders are responsible for is also provided in this report to assist them in developing a coordination plan.

As for the **storage pillar (Chapter 5),** CO_2 storage potential is evaluated primarily in three geological media: saline aquifers, depleted oil and gas reservoirs, and coal beds with **three identification phases to be identified: (i) storage location, (ii) storage capacity and (iii) storage suitability**. Although all of the AMS are still in the early stages of developing their CO_2 storage projects, **five countries, namely Indonesia, Malaysia, Philippines, Thailand and Viet Nam have completed all three steps of the identification phase**, with seven having at least reached a realistic/effective CO_2 storage capacity assessment level which is one level above the theoretical capacity. To better identify storage capacity, access to storage or geological data must be open. **Effective collaboration and the sharing of information and plans** among stakeholders would significantly impact the effectiveness and accuracy of CO_2 storage characterisation.

As for the **key challenges of CCS deployment (Chapter 6)** in the region**, economic viability** is found to be the most difficult one to resolve. Most of AMS representatives believe that the high costs of CCS technologies (especially the upfront costs) are prohibitive, but that financial support could become available from carbon pricing and/or the provision of subsidies, grants and procurement-based contracts. **Long lead times and project complexity** (including project risk) are other key challenges that need to be addressed. Finally, solving the wide innovation gaps is also crucial if CCS projects in ASEAN are to become viable.

From the above pillar frameworks aligned with the key challenges of CCS deployment, the following recommendations are proposed as part of the ASEAN CCS Roadmap Deployment:

- **Enhancing the economic viability of CCS development with aim** to reduce the high capital costs and improve the competitiveness of CCS compared to other emerging technologies. Key measures include: (i) implementing carbon pricing to support the local CCS ecosystem, (ii) providing financial incentives such as grants and tax credits, and (iii) offering revenue support through contracts and procurement processes. Engaging state-owned utilities in CCS projects during the short and medium terms is also essential.
- **Shortening the lead times of CCS projects and accelerating the domestic deployment of CCS** through fostering close coordination among stakeholders when they formulate the plans, timelines and targets for CCS deployment in ASEAN. These efforts need to be continued through the medium and long terms, especially when it comes to setting clear regulations for the permitting and licensing of CCS projects including transboundary CO_2 movements in the region.

- **Managing project complexity and derisking CCS deployments** through a top-down approach which aims to strengthen legislation, public policies and regulations related to CCS projects in the region. Over the short-term stage (the market creation stage), a robust legal framework is needed to define and classify CO_2, including its ownership across the CCS value chain. Long-term post-site closure regulations and financial assurances are also necessary. In the mid-term, the necessary actions include ensuring storage site safety, conducting leakage risk assessments and harmonising regional technical codes and safety standards. By the end of the long-term period, ongoing monitoring and maintenance of CCS projects are recommended. This must involve public engagement with all the relevant stakeholders set by the government.
- **Narrowing the technology innovation gaps** by conducting feasibility studies on technological readiness, socio-economic impacts, and greenhouse gas emissions during the short-term period. In the medium and long terms, the establishment of standards and certifications for CO_2 removal (CDR) and their inclusion into the legal and regulatory framework of CCS are essential for reliability, effectiveness and safety.
- **Facilitating CCS hubs and international transboundary CO_2 movements** by establishing in the short term a CCS database to map potential source and sink locations, as well as CCS hubs in the region. The regulation regarding access to shared transport and storage infrastructure, cross-border CO_2 transportation, and compliance with international law needs to be developed fully during the medium term. To support the smooth implementation of measures for the long term, a close coordination among relevant stakeholders is necessary.

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List of Abbreviations

ACE	ASEAN Centre for Energy
ADB	Asian Development Bank
AMEM	ASEAN Ministers on Energy Meeting
AMS	ASEAN Member States
ANPM	*Autoridade Nacional do Petróleo e Minerais* (National Petroleum and Minerals Authority)
APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of Southeast Asian Nations
ATS	AMS Target Scenario
BECCS	Bioenergy with Carbon Capture and Storage
BPMA	*Badan Pengelola Migas Aceh* (Aceh Oil and Gas Management Agency)
CAPEX	Capital Expenditure
CCfD	Carbon-Contracts for Difference
CCMP	Climate Change Master Plan
CCS	Carbon Capture and Storage
CCT	Clean Coal Technology
CCUS	Carbon Capture, Utilisation, and Storage
COP	Conference of the Parties
CPI	Carbon Pricing Instruments
CSLF	Carbon Sequestration Leadership Forum
DAC	Direct Air Capture
DGP	Depleted Gas Reservoir
DMF	Department of Mineral Fuels
DOE	Department of Energy
DOGP	Depleted Oil and Gas Reservoir
DOP	Depleted Oil Reservoir
DPR	*Dewan Perwakilan Rakyat* (House of Representatives)
DSF	Deep Saline Formations
ECBM	Enhanced Coalbed Methane
EDB	Economic Development Board
EDGAR	Emissions Database for Global Atmospheric Research
EGR	Enhanced Gas Recovery
EMA	Energy Market Authority
EOR	Enhanced Oil Recovery

ESG	Environmental, Social, and Governance
ETS	Emission Trading Systems
EU	European Union
EUR	Estimated Ultimate Recovery
EVN	Viet Nam Electricity
FDIS	Final Draft International Standard
FEED	Front-End Engineering and Design
FGD	Focus Group Discussion
FID	Final Investment Decision
FID	Final Investment Decision
GBIC	Green Buildings Innovation Cluster
GCCSI	Global Carbon Capture Storage Institute
GDP	Gross Domestic Product
GHG	Green House Gas
GW	Giga Watt
ICC	International Carbon Credits
ICCSC	Indonesia Carbon Capture and Storage Center
ICP	Internal Carbon Pricing
IDX	Indonesia Stock Exchange
IEA	International Energy Agency
IMF	International Monetary Fund
ISO	International Organisation for Standardization
ITB	*Institut Teknologi Bandung* (Bandung Institute of Technology)
JAPEX	Japan Petroleum Exploration
JETP	Just Energy Transition Partnership
JOGMEC	Japan Organization for Metals and Energy Security
Lao PDR	Lao People's Democratic Republic
LCER-FI	Low-Carbon Energy Research Funding Initiative
LEMIGAS	*Lembaga Minyak dan Gas Bumi* (Oil and Gas Institute)
LNG	Liquefied Natural Gas
LOI	Letter of Intent
LP	London Protocol (including all of its amendments)
LPG	Liquefied Petroleum Gas
LT-LEDS	Long-Term Low Greenhouse Gas Emission Development Strategy
MC	Mitsubishi Corporation
MEMR	Ministry of Energy and Mineral Resources

METI	Ministry of Economy, Trade and Industry
MoEF	Minister of Environment and Forestry
MOFA	Ministry of Foreign Affairs
MPa	Million Pascal
MRV	Monitor, Reporting, and Verification
MSME	Micro, Small, and Medium Enterprises
Mt	Million Ton
MTPA	Million Tonnes Per Annum
MW	Mega Watt
NDC	Nationally Determined Contributions
NETR	National Energy Transition Roadmap
NGCC	Natural Gas Combined Cycle
NRF	National Research Foundation
NSCC	National Strategy on Climate Change
NZE	Net Zero Emissions
OGIP	Original Gas in Place
OJK	*Otoritas Jasa Keuangan* (Financial Service Authority)
OOIP	Original Oil in Place
OPEX	Operating Expenditure
PAU	Panca Amara Utama
PEMA	PT Pembangunan Aceh
PETRONAS	Petroliam Nasional Berhad
PPP	Public-Private Partnership
PTBAE	Pagu Tingkat Batas Atas Emisi
PTTEP	Petroleum Authority of Thailand Exploration and Production Public Company Limited
PVN	Petro Viet Nam
SEACA	Southeast Asia CCS Accelerator
SKK Migas	*Satuan Kerja Khusus Pelaksana Kegiatan Usaha Hulu Minyak dan Gas Bumi* (Special Task Force for Upstream Oil and Gas Business Activities)
SOE	State-Owned Enterprise
TPES	Total Primary Energy Supply
TSC	Technical Screening Criteria
UNCLOS	United Nations Convention on the Law of the Sea

Chapter 1

Introduction

1.1 Overview of ASEAN's energy demand and supply

The region's population has always represented a notable share of the global population, and according to the 8th ASEAN Energy Outlook (2024) Scenario, the population will reach 787 million in 2050, up from 668 million in 2020 [1]. Economically, ASEAN has shown impressive growth in recent years, and the real GDP (at 2017 constant price) is expected to expand 3.2 times by mid-century from 2020 as depicted in **Figure 1.1** [1]. Due to the expected large population increase and rapid economic growth, ASEAN's energy demand is projected to triple by 2050.

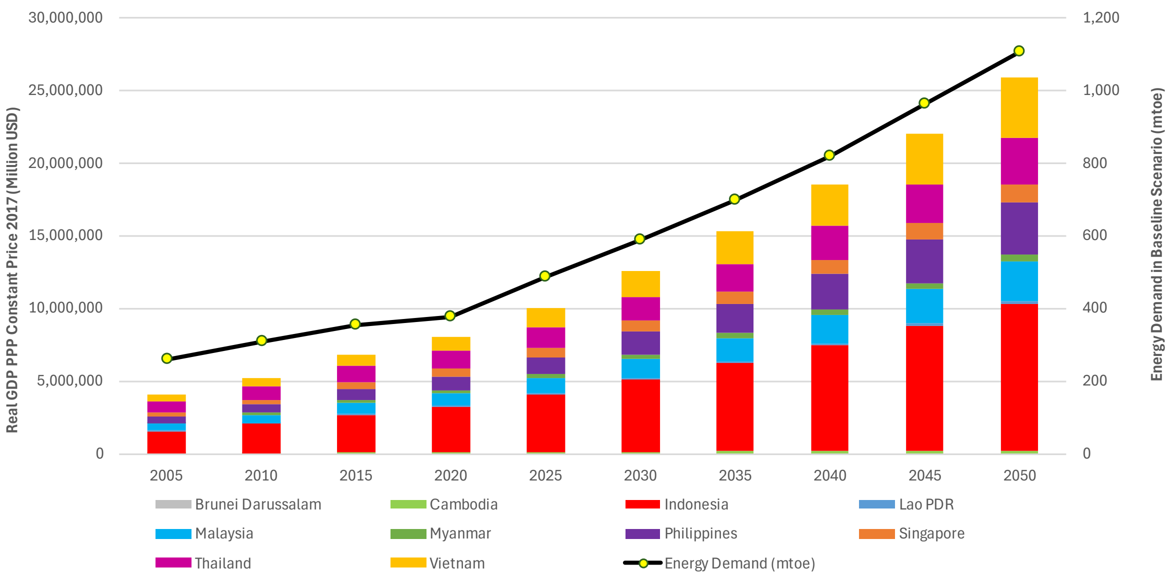


Figure 1.1 ASEAN Real GDP and Energy Demand, 2005-2050
Source: [1].

The region's economic and population growth have been two key factors in its heavy reliance on fossil fuels, a trend that is likely to continue. Oil remains the primary energy source, currently constituting about 42% of energy demand, followed by electricity at nearly 22% [1]. Efforts to achieve universal access to electricity have fuelled this increase. As shown in **Figure 1.2** the industrial and transportation sectors are the most energy-intensive, accounting for a significant portion of the region's energy consumption. Industrial energy demand has nearly doubled since 2005 [1], reflecting ASEAN's ongoing development and economic activity.

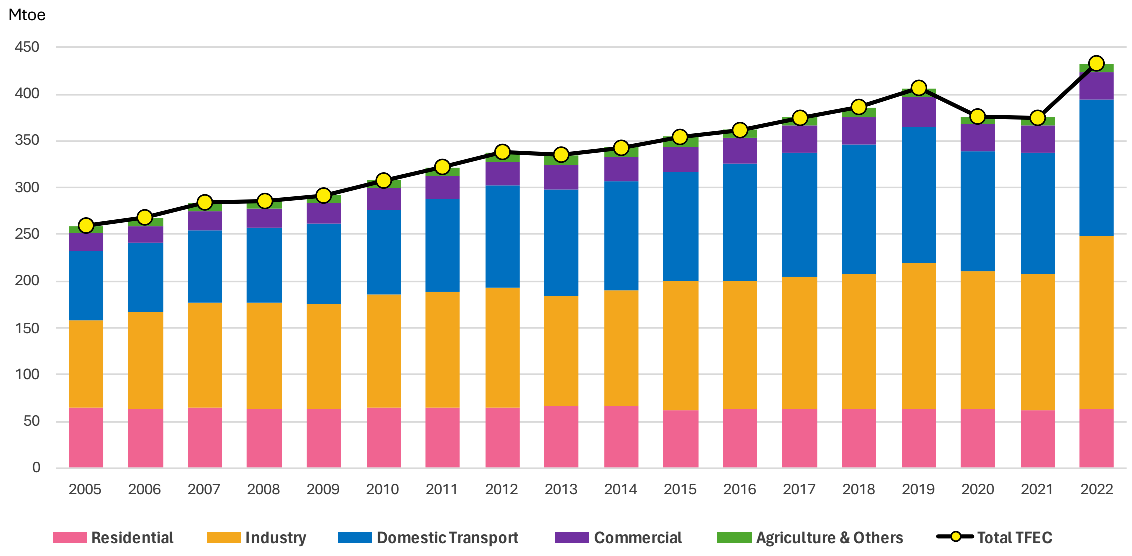


Figure 1.2 ASEAN's total final energy consumption by sector, 2005-2022
Source: [1].

To meet the growing demand for energy, **Figure 1.3** shows that ASEAN's total primary energy supply (TPES) is set to increase sharply, rising from 698 Mtoe in 2022 to 1,822 Mtoe by 2050 [1]. Fossil fuels have historically dominated the region's energy mix, accounting for about 82% in 2022 [1]. Despite efforts to promote the use of renewable energy and increase energy efficiency, fossil fuels are likely to dominate the energy mix over the next few decades. This historical trend is expected to continue, with oil, natural gas and coal making up around 76% of the TPES by mid-century in 2050 [1].

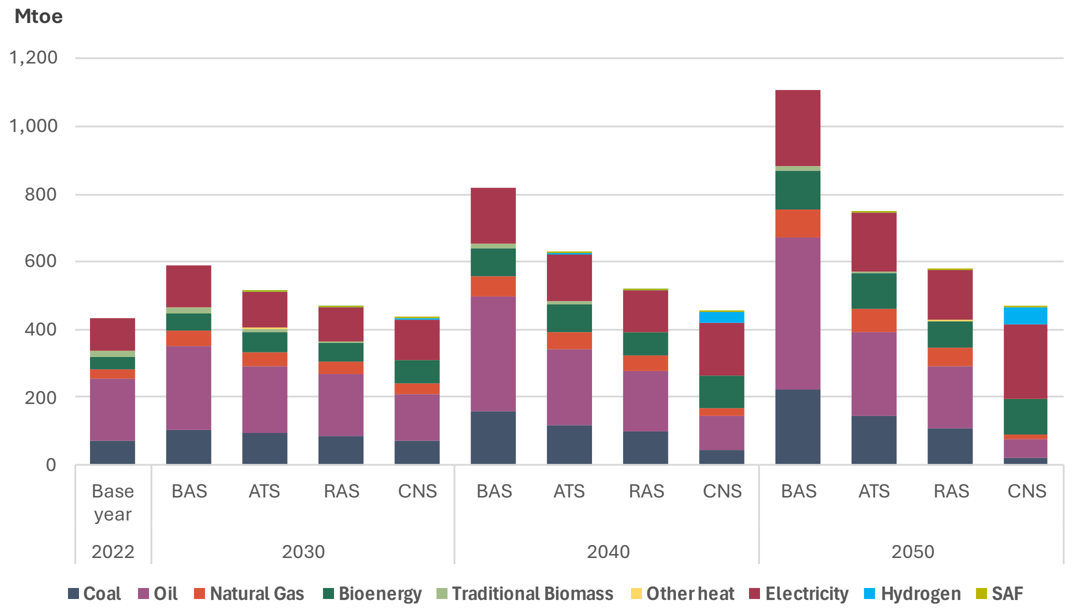


Figure 1.3 ASEAN's energy supply projection by fuel across scenarios
Source: [1].

Although the combined share of fossil fuels in the power sector shows a declining trend, it will continue to dominate. Specifically, coal contributed 43% to the generation mix in 2019, followed by natural gas at 34% [1]. The total installed coal-fired power plant capacity is projected to nearly double, increasing from 107 GW in 2022 to around 113 GW by 2050 in the AMS Target Scenario (ATS). By then, coal is expected to constitute more than one-quarter of the total power generation [1].

However, sectoral analysis reveals a significant shift in coal usage, with industrial demand rising sharply while power generation demand declines [1]. Coal will be used primarily for industrial heat, power generation and other transformations (including the industry's own use and losses). The industrial sector's demand for coal is expected to grow by 104% from 2022 to 2050. Conversely, coal's share in power generation will decline by 20% over the same period, as it is increasingly replaced with natural gas and renewables.

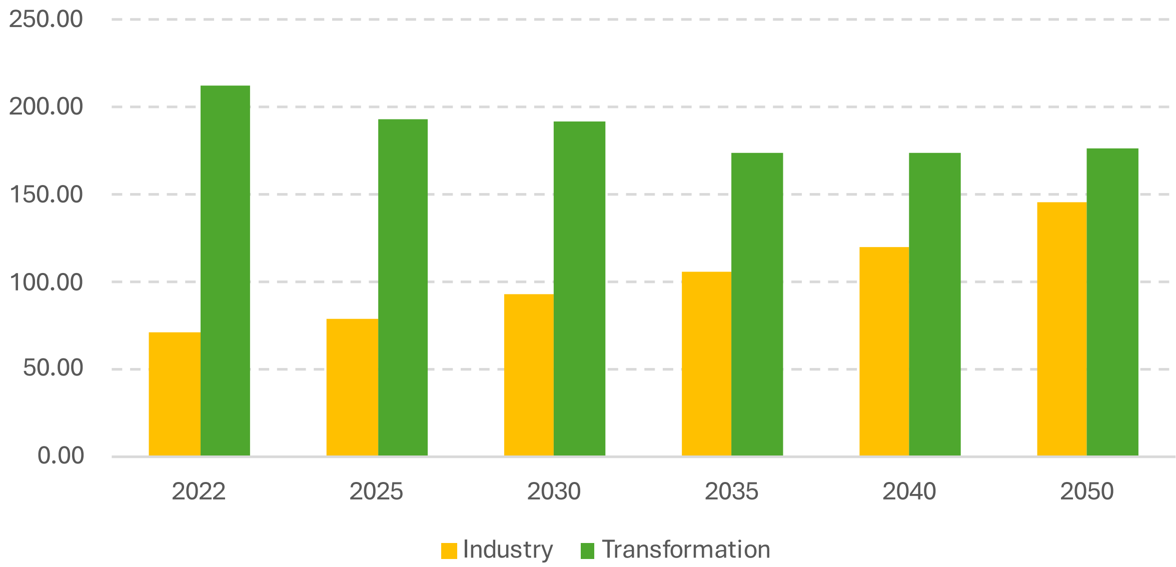


Figure 1.4 Projections of transformation and final demand for coal in ASEAN by sector in Mtoe (ATS Scenario)
Source: [1].

1.2 Greenhouse Gas Emission Trends in ASEAN

Significant environmental challenges are presented by ASEAN's rapid population and economic growth. A major issue is the increase in greenhouse gas (GHG) emissions which contribute to global warming and climate change. Due to its unique economic and social characteristics, long coastlines, and mostly tropical climate, is the AMS are particularly vulnerable to the effects of climate change. Their energy-related GHG emissions totalled 2,215 million metric tons of CO_2 equivalent in 2020 [1].

Among the greenhouse gases, carbon dioxide (CO_2) accounts for the largest share of ASEAN's emissions at 72%. In 2022, the AMS emitted 1.96 gigatonnes of CO_2, or 5% of the global total [2]. The high level of CO_2 emissions in this region underscores the critical need for all of the AMS to pursue carbon neutrality—achieve zero net CO_2 emissions—as an essential step towards net-zero emissions, which also includes other GHGs like methane and nitrous oxide [3].

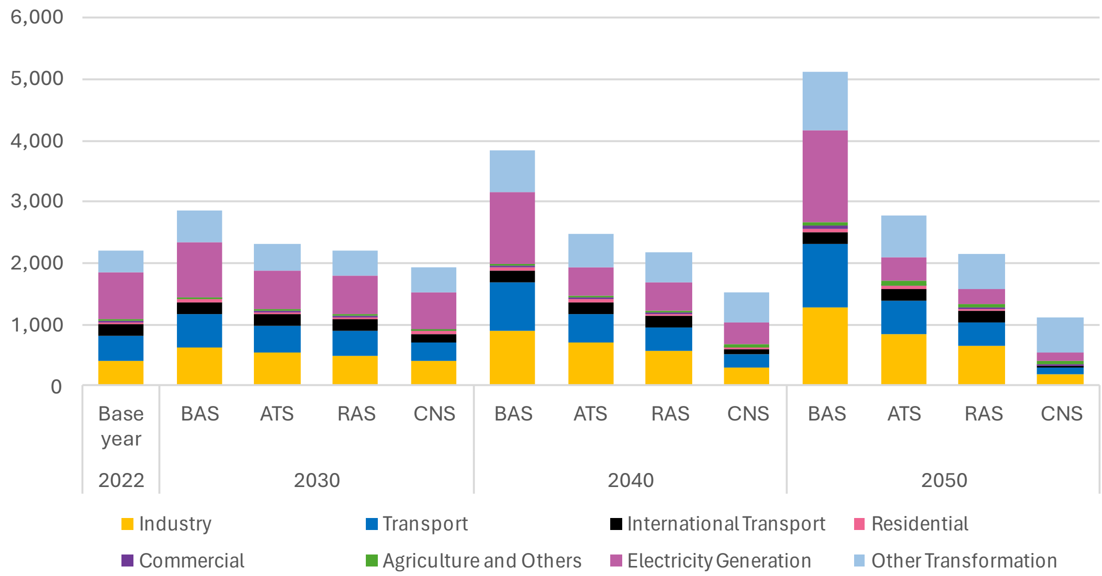


Figure 1.5 GHG emissions produced by sector in the Baseline Scenario in $MtCO_2$-eq, 2005-2050
Source: [1].

Power generation and transformation processes are the primary sources of GHG emissions, accounting for approximately 51% of total energy-related emissions in 2022 [1]. Industry and transportation come next, each accounting for about 18%. Through 2050, these industries are predicted to continue contributing the largest shares of emissions. The carbon emissions from these industries are expected to rise significantly as they expand. Total emissions are expected to double by 2050 compared to 2020 levels [1], highlighting the critical need for ASEAN to take effective climate action.

1.3 The Role of CCS in ASEAN's Energy Landscape

Given the high potential for both the capture and storage of carbon, there is momentum for CCS to expand in the region. The strong history of regional cooperation within ASEAN is also motivating the development of large, shared CCS infrastructure, with the goal of creating a CCS hub.

This was acknowledged during the 41st ASEAN Ministers on Energy Meeting (AMEM) in 2023, which supported ASEAN's commitment to emissions reduction through the deployment of carbon capture technology and carbon capture, utilisation and storage

(CCUS) [4]. The meeting also agreed to take further steps to realise cross-border carbon transport and storage, and support the development of regional carbon markets, enhancing the economic and technical feasibility of CCS projects in the region.

CCS is also part of ASEAN's broader strategy discussed in the ASEAN Strategy for Carbon Neutrality 2023 [3] to accelerate the integration of green value chains, foster cooperation and remove trade barriers among the member states to expedite the market entry of green products, including captured carbon, and potential carbon storage facilitated through CCS hubs. The underlying goal is to develop a coordinated approach to regional policy frameworks and regulations, paving the way for CCS infrastructure development in ASEAN.

ASEAN has also integrated this technology into its strategic plans. The ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021-2025 outlines initiatives to promote clean coal technology (CCT) and CCS as part of the energy transition towards a low-carbon economy [5]. Under Programme Area No. 3 (Clean Coal Technology), specifically Action Plan 1.4, ASEAN underscores the importance of developing a "CCS Deployment Framework and Roadmap for ASEAN". This initiative is aligned with the priorities of the 2022 Cambodia Chairmanship which are continued under the 2023 Indonesia Chairmanship and the 2024 Lao PDR Chairmanship.

Furthermore, the AMS have recently updated their Nationally Determined Contributions (NDCs) in adherence to the Paris Agreement, committing to reduce GHG emissions by 2030. This collective effort is geared towards limiting the global temperature rise to 1.5°C [6], reflecting each member state's specific conditions and contributions. Following the 26th Conference of Parties (COP26) in 2021, nine AMS pledged to achieve net-zero emissions over the long term [1].

In 2023, ASEAN launched the ASEAN Strategy for Carbon Neutrality document, which notes that several mitigation measures are planned to meet the targeted emission. It also discusses the deployment of CCS technologies, identifies potential CCS hubs and calls for policy support to enable cross-border CO_2 transportation [3]. The document notes that the region's coal power plants are relatively young, with many years of economic life still ahead. As they expand, the CO_2 emissions will surely increase if no mitigation measures are applied [7].

Hard-to-abate heavy industries (like cement, iron and steel, and chemical production) need to receive extra attention due to their high energy consumption. Globally, heavy industry accounts for more than 17% of CO_2 emissions, with cement alone accounting for 8% and iron and steel for 7%. All of these industries emit over twice as much CO_2 as the aviation (2.5%) and shipping (3%) sectors combined [8]. Within ASEAN, they account for approximately 20% of all the energy-sector emissions [3]. Viet Nam and Indonesia are among the world's top five cement producers, and as the AMS industrialise further, the emissions from the steel industry will surely rise [3].

What Is CCS?

Carbon Capture and Storage (CCS) refers to a suite of technologies that involves **capturing carbon emissions** and **storing the captured carbon.**

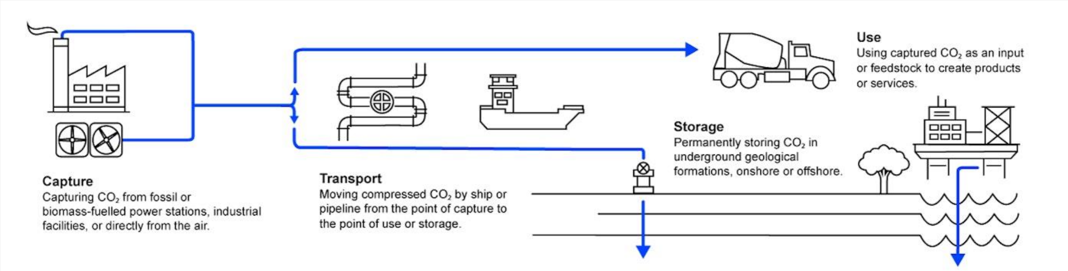


Figure 1.6 CCS value chain
Source: [9].

Carbon Capture

Before it reaches the atmosphere, the emitted CO_2, from large point sources like power generation or industrial facilities that are fuelled by either fossil fuels or biomass, is captured using technologies that separate it from other gaseous emissions so it can be economically stored. There are four basic types of CO_2 -capture engineering approaches: pre-combustion, post-combustion, oxyfuel combustion and inherent combustion processes [10].

Carbon Storage

If not used, the captured carbon can be permanently stored in geological formations such as deep saline aquifers, depleted hydrocarbon reservoirs and various unconventional storage locations. Prior to being stored, the captured CO_2 must be compressed and moved by pipeline, ship, rail or truck.

CCS technologies help economies transition from the current energy mix towards a more carbon neutral one. Retrofitting CO_2 capture equipment allows plants to continue operations while emitting less CO_2. This will greatly benefit most of ASEAN's power plants which are still relatively young and have many years of service ahead [11]. CCS will also help the AMS achieve energy security goals by promoting diversity in generation options and integrating variable renewables with flexible dispatchable power. In emissions-intensive industries, retrofitting facilities with CCS will maintain economic prosperity and job opportunities while preventing the negative social and economic effects of early retirements [12].

Production routes based on CCS are currently the most advanced and least expensive low-carbon options in the industrial sector, such as the iron and steel sector, to produce virgin steel, which accounts for about 70% of global steel production. When it comes to chemicals, CCS is frequently deemed the least expensive way to cut emissions from the methanol and fertiliser (ammonia) production processes. CCS is also the only way to address CO_2 emissions from natural gas processing [12] which will undoubtedly continue throughout ASEAN's energy systems over the coming decades.

1.4 Scope and Structure of the Report

To accelerate CCS deployment to support the region's carbon neutrality targets, this strategic report aims to develop a CCS deployment framework by examining the existing conditions of the above-mentioned three key CCS pillars in ASEAN: (i) policy; (ii) legal and regulatory framework; and (iii) storage.

The pillars are based on the discussions conducted in 2023 at two Southeast Asia CCS Accelerator (SEACA) workshops organised by the Global CCS Institute (GCCSI) in collaboration with the ASEAN Centre for Energy (ACE). To assess the current situation and necessary actions to accelerate the deployment of CCS in supporting efforts towards ASEAN's carbon neutrality target, this study employed the IEA Frameworks on the three pillars, with detailed assessments based on desk research and complemented by an online questionnaire and closed focus group discussions (FGDs) with the AMS representatives. The overall structure and analytical flow of each pillar in the report are summarised in **Figure 1.7**

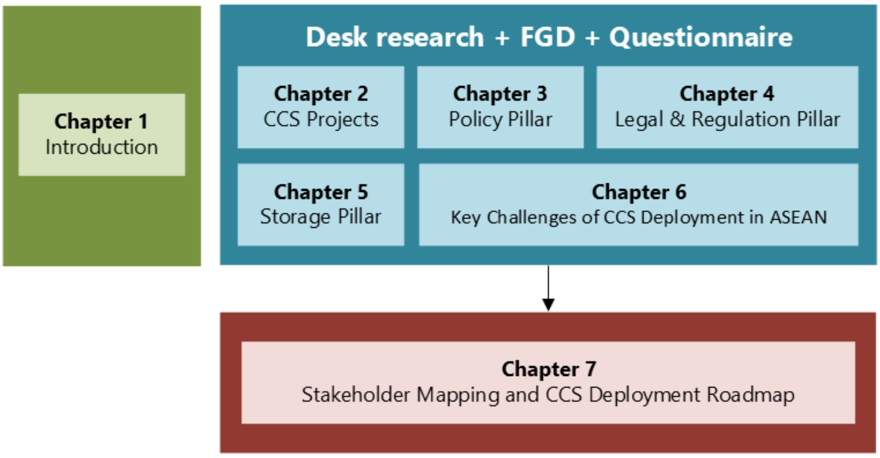


Figure 1.7 Structure and analytical flow of the report

Chapter 1 – Introduction

Chapter 1 sets the context and background relating to the important role of CCS deployment in ASEAN in the context of the energy landscape, emissions and energy transition pathways of the region. Understanding the region's energy landscape, including its future energy demand and supply is a crucial step to identifying its long-term energy needs. With its significant dependence on fossil fuels, the region needs to formulate its energy transition pathways gradually. Hence, it is a good time to formulate a CCS deployment framework and roadmap, laying out the necessary steps for the short- medium-, and long-term periods.

Chapter 2 – Overview of CCS Projects in ASEAN

To provide an overview of CCS deployment status in the region, Chapter 2 identifies the existing CCS projects (and pilot projects) across the ASEAN region.

Chapter 3 – CCS Policy Pillar

Chapter 3 reviews the key elements of the CCS policy pillar in ASEAN based on the IEA Framework on CCUS Policies and Business Model adjusted into the regional context. The CCS policy pillar discussed in this chapter consists of five key elements: (i) enabling policies, including enabling legislation and rules, (ii) cost reduction measures, (iii) regulation of industrial activities, (iv) strategic signalling, and (v) revenue support.

Chapter 4 – CCS Legal and Regulatory Framework Pillar

Chapter 4 examines the presence of a CCS legal and regulatory framework in both ASEAN as a whole and in each AMS. It also examines the existing CCS legal and regulatory framework based on the seven key elements of the IEA CCS legal and regulatory framework: (i) environmental reviews and permitting; (ii) enabling first mover projects; (iii) ensuring safe and secure storage; (iv) addressing long-term storage abilities; (v) handling of international and transboundary issues; (vi) facilitating CCS hubs; and (vii) managing other key emerging issues (such as treatment of CO_2 removal and others). The results of desk research pertaining to the CCS legal and regulatory framework pillar are then used as basic information to be further explored and complemented by the results of the questionnaire and focus group (FGD) summaries.

Chapter 5 – CCS Storage Pillar

Chapter 5 discusses the existing storage facility development in ASEAN and its key elements. It identifies the level of geological storage assessment done by each AMS, including the identification of storage locations and their capacity and suitability; technical assessment for leakage, transportation and hubs; and socio-economic risk assessment. This chapter also discusses the urgency for ASEAN to establish a storage database to ease the resolution of cross-boundary issues, including CCS hubs and networks.

Chapter 6 – Key Challenges Faced in ASEAN's Deployment of CCS

This chapter identifies the key challenges which the AMS face in developing and deploying CCS technologies. It employed the IEA framework on CCUS Policies and Business Model, as well as the outcomes of the FGDs and questionnaire. The key challenges are grouped into three categories: (i) economic viability; (ii) innovation gaps; and (iii) project design.

Chapter 7 – CCS Deployment Roadmap in ASEAN

Chapter 7 presents a CCS deployment roadmap for ASEAN with the steps divided into the short, medium and long terms. Before proposing the roadmap, a stakeholder map is developed based on the case study of Indonesia's CCS stakeholders. It was developed on the basis of the key insights learned through desk research, the questionnaire and FGD. This roadmap outlines the necessary steps and timelines for ASEAN to accelerate the deployment of CCS projects from inception to the commercial phase. This chapter concludes with suggestions to realise ASEAN's CCS roadmap.

Chapter 2

Overview of Existing CCS Projects in ASEAN

With an estimated total of 143 oil and gas fields in Viet Nam, Thailand, Philippines and Indonesia (South Sumatra), offering 3.5 Gt of CO_2 storage capacity in 2023, ASEAN has wide potential for the deployment of CCS [13]. Another advantage that Southeast Asia has is its lower cost of storage compared to the global benchmark. McKinsey reported that storage costs in ASEAN are 65% lower than the global average [14].

At present, there are at least 24 existing CCS projects across the region (see **Table 2.1**). **Indonesia** has become the lead country actively pursuing the study and preparation phases of 19 CCS projects, with an estimated capacity of 9.84 Mt CO_2/year. Indonesia, Malaysia and Thailand deployed full-chain operation for CCS that almost entirely covered the LNG industry. Singapore recently joined the CCS ecosystem and announced the appointment of S-Hub (a consortium comprising Shell and ExxonMobil) to study the viability of developing a cross-border CCS project in 2024. Indonesia and Singapore soon thereafter signed a Letter of Intent (LOI) on Cross-Border CCS and plan to set up a workgroup to discuss CCS cooperation between Singapore and Indonesia.

The development of CCS in **Indonesia** began with the establishment of the National Center of Excellence on CCS in 2017, which brought together experts from the Bandung Institute of Technology (ITB) and the research centre of the Ministry of Energy and Mineral Resources (LEMIGAS) [17]. It resulted in Indonesia's first full chain project, the Abadi CCS to be operational by 2027, with a capacity of 2.41 Mt CO_2/year. Among the AMS, Indonesia has gained the most experience relating to the full chain project that linked EOR/EGR in the Gundih CCUS EGR with the Sukowati CO_2-EOR [15].

The region's first CCS pilot project came into being in Indonesia in 2012 at the Gundih Gas Field in Central Java. It was a collaboration between J-POWER & Japan NUS Co and PT Pertamina aimed at demonstrating the storage of up to 0.3 million tonnes of CO_2 per year at the Gundih Gas Field. It involves capturing CO_2 emissions from a gas processing plant at the Gundih Gas Field and transporting it via pipeline to an underground storage reservoir created from a deep saline formation located approximately 2.5 kilometres beneath the ground. This project received funding from the CCS Fund of the Asian Development Bank (ADB) to carry out a feasibility study, including risk assessments, project management plans and the development of a CCS legal and regulatory framework [10].

Table 2.1 Summary of existing CCS projects in ASEAN

	Indonesia	Malaysia	Singapore	Thailand	Viet Nam
Total Projects	19	2	1	1	1
Project type	9 storages, 9 full chains, 1 capture	Full chain	Full chain	Full Chain & Storage	Offshore Oil and Gas
Estimated Capacity	9.84 Mt CO_2/year	3.3 Mt CO_2/year	2.5 Mt CO_2/year		71 Gt CO_2*
Announcement	2018-2024	2020-2022	2024		
FID	2024-2025	2022			
Operation	2025-2032	2025	2030		
Industry	4 Storages; 2 Power Heats; 1 Other fuel transformations; Natural gas processing/ LNG;	Natural gas processing/LNG	Hard-to-abate sectors such as Energy & Chemicals, power and waste	Storage	Offshore Oil and Gas
Fate of Carbon	9 Dedicated Storages; 5 EORs; 4 unspecified	Dedicated Storage	Storage, to be identified		EOR
Notable Projects	Gundih CCS, Sakakemang, Sukowati CCUS, Arun, Tangguh CCUS Hub	Kawasari, Lang Lebah, Shepherd	Establishment of S-Hub to develop cross-border CCS	PTTEP Arthit	Rang Dong

Sources: [15] [16].

To commence operations in 2025, the Sukowati Project in Indonesia will be the first full chain project in the region. Sukowati CO_2-EOR was developed through an agreement between PT Pertamina Indonesia, LEMIGAS and Japan Petroleum Exploration (JAPEX). The target is for it to reach its full scale in 2031, potentially storing 7-14 million tCO_2 for 15 years [18].

From the Jepon-1 (JPN-1) site at Gundih Field, a report was published listing the lessons learned from the JPN-1. It noted the urgent need to develop a more robust monitoring, reporting and verification (MRV) system, and to greatly improve the quantity and quality of data [19]. It stated that standards alone were inadequate to evaluate the integrity of the well due to the need to specify criteria, duration of measurement and range of measurement parameters of the available tools according to industries' best practices. The wells were not up to international standards and the MRV system at the national level was found to be still limited. A leakage occurred which could not be explained due to the lack of data.

Another CCS project is the Sakakemang Block, South Sumatra, Indonesia which is expected to commence operations in 2026. It is a joint project among Repsol, which serves as an operator and holds a 45% working interest, Malaysia's Petronas which holds 45% and MOECO which holds the remaining 10%. The Repsol company is currently waiting for the issuance of an Indonesian presidential regulation, as well as derivative regulations. This project is expected to capture 2 million tonnes of CO_2 per year. The Sukowati CCS project reached an agreement in 2021 between Japan Petroleum Exploration (JAPEX), PT Pertamina Power Indonesia and LEMIGAS. The three parties will consider the possibility of a demonstration test for the transportation of CO_2 from a nearby gas field using a supercritical CO_2 pipeline, and injection and storage of CO_2 into the oil reservoir of the Sukowati Oil Field. This project is to be conducted under the joint crediting mechanism (JCM) of the Japanese Government and will capture an estimated 1.4 million tonnes of CO_2 per year [16].

Another major CCS project in Indonesia is the Arun CCS Project in the Aceh gas field. Aiming to commence in 2029, it is under the PEMA Aceh Carbon Joint Venture created to assess and repurpose the depleted Arun Gas Field for CCS purposes. It has the potential to become Asia's inaugural commercial CCS business, offering open access storage of CO_2 [20].

As of 2022, Indonesia had 15 CCS projects still in the preparation stage, with three additional ones announced for the following year. Work on the Tangguh CCUS hub began in 2023. It will originate from the Port of Nagoya, Japan and culminate in CO_2 storage in offshore West Papua, Indonesia [21]. With an ultimate storage capacity of 1.8 $GtCO_2$, it is strategically positioned and has the potential to become Indonesia's primary CCS hub for both domestic and international emitters [22].

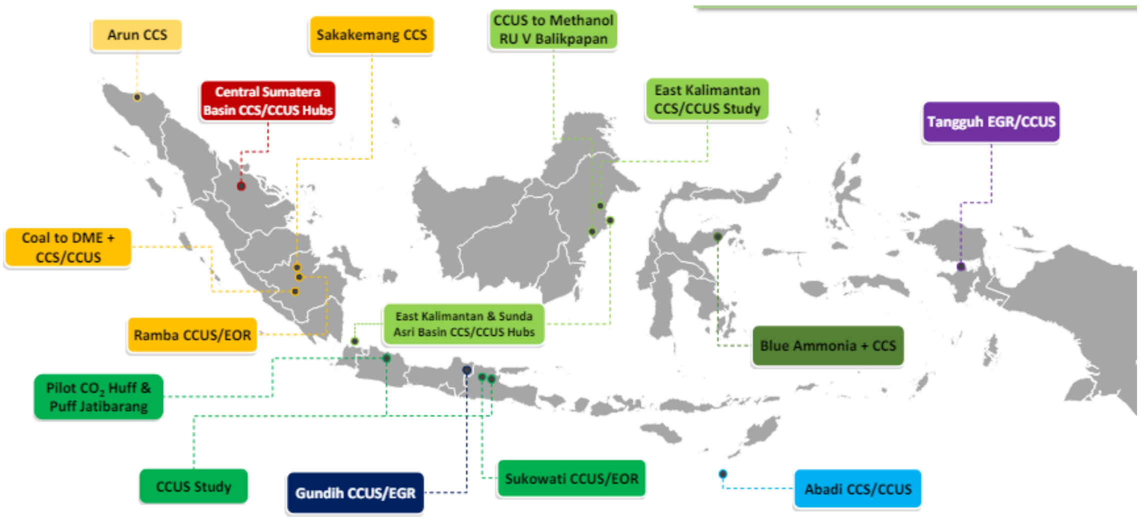


Figure 2.1 Map of CCS projects in Indonesia as of 2022
Source: [18].

Malaysia is actively developing a significant CCS project with an approximate capture capacity of 3.3 Mt CO_2/year. The Kasawari Gas Field CCS project was announced in 2020 and is expected to begin operations by the end of 2025. Located off the coast of Sarawak in Block SK316, around 200 km off Bintulu, it is owned by Petronas Carigali, a subsidiary of the Malaysian state oil firm, Petronas. The final investment decision (FID) was taken in November 2022. This project represents a major milestone in Malaysia's efforts to decarbonise its energy sector and achieve net-zero emissions by 2050 [23]. It underscores Malaysia's potential to become a regional hub for CCS solutions, with an anticipated injection of up to 3.7 Mtpa of CO_2 and storage of roughly 80 Mt of CO_2 over 25 years of operation. Involving the construction and installation of a fixed offshore platform, with compressed CO_2 being reinjected into the depleted reservoir at the M1 Field via a 138 km long 16-inch subsea pipeline, it aims to reinject around 71 to 76 million tonnes of CO_2 using Petronas' technologies, such as the PN2 Hollow Fiber Membrane and cryogenic distillation technology for high CO_2 concentration. This large-scale project, representing 9% of global CCS operations in 2021, anchors PETRONAS' pathway for net-zero carbon emissions by 2050.

Other Projects in Malaysia are the Shepherd and Lang Lebah Projects, which will commence in 2025 and 2026, respectively. The Shepherd CCS Project is a Korea-Japan joint effort which was announced in August 2022. It aims to capture CO_2 emissions from Korea's industries and transport them to Malaysia to be stored. Six South Korean companies, namely SK Energy, SK Earthon, Samsung Engineering, Samsung Heavy Industry, Lotte Chemical and GS Energy, signed a memorandum of understanding (MoU) with Petronas. Shell Gas & Power, Air Liquide Korea, Hanwa Corporation and Korea National Oil Corporation also joined the MoU a year after the signing. Currently, the Korean and Malaysian companies are conducting a feasibility study for the project and have tentatively determined several domestic hubs to collect carbon emissions in Korea and a storage site in Malaysia [16].

Malaysia is awaiting the completion of a CCS project with a capacity of 3.3 Mt CO_2/year planned for PTTEP's Lang Lebah Offshore Field. Gas produced from Lang Lebah will be transported via pipeline to an onshore processing facility named OGP-2 [24]. Subsequently, the extracted CO_2 will be piped offshore for injection into the depleted Golok Field. Another project in Malaysia is Bujang, Inas, Guling, Sepat and Tujoh or BIGST Gas Fields Cluster Heads of Agreement, which was announced in 2022 through a joint proposal by Petronas and JX Nippon [15]. The project aims to monetise the gas potential and develop the first CCS project in Peninsular Malaysia.

Meanwhile, **Thailand** recently followed Malaysia's steps to initiate its first national full-chain CCS project in 2021 through the Arthit offshore gas field. Thailand's national petroleum company, PTTEP, is leading the project and has allocated a budget of USD 300 million. It has conducted a feasibility study on the assessment of carbon storage capacity in targeted geological storage formations and developed an associated conceptual development plan. Currently, the project is in the preliminary front-end engineering and design (pre-FEED) stage, with operations anticipated to begin by 2026. The project aims to store up to 1 million tonnes of CO_2 during gas production at Arthit. In addition, PTTEP has collaborated with Japanese businesses experienced in CCS technologies to evaluate the possibility of CCS development in other regions of Thailand [25].

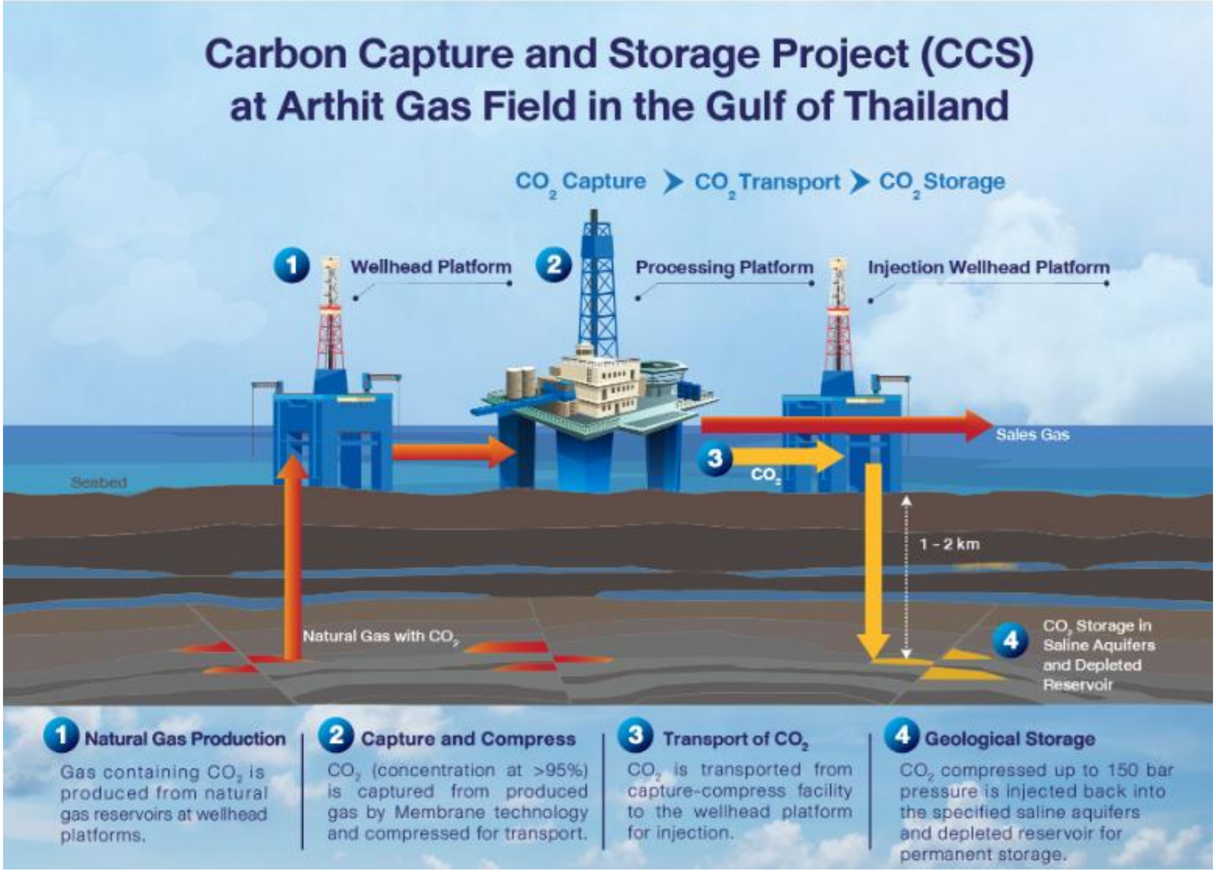


Figure 2.2 CCS project at the Arthit Gas Field
Source: [26].

In 2011, **Viet Nam** became the first country in ASEAN to effectively execute a project aimed at enhancing oil recovery using CO_2 at the Rang Dong Field in Block 15-2 of the Cuu Long Basin. This CO_2-EOR project is expected to increase oil production from 950 to 1,500 barrels per day and has potential to store CO_2. To comprehend the applicability of CO_2-EOR linked with CCS, the Viet Nam Oil and Gas Group (PVN) and JOGMEC carried out an international cooperative study on the plan of an interwell CO_2-EOR pilot test at an offshore oil field in the country [27].

Seven large-scale CCS projects have been identified in Southeast Asia, with several linked to natural gas processing with offshore storage. For countries with CCS pilot projects, like Indonesia, the challenges are the need for more technical human resources to manage the deployment, resulting in delayed results of the assessment phase [19].

A pilot CCS project in Central Java, Indonesia (Gundih Gas Field), has been undertaken to assess the feasibility of CCS. If successful, the ADB's pilot studies are expected to take around five years to be completed in Indonesia [29]. However, the projects have needed three extensions due to several challenges:

1. Structural integrity issues of the proposed injection well.
2. Questionable geologic suitability for CO_2 storage.
3. Broader technical expertise needed, causing additional individual consultants to be engaged to support these activities.

According to ISO 27914 and ISO/FDIS 27916, the design and construction of an injection well must guarantee safety and the ability to contain the stored CO_2 over a long-term period. However, the causal factors go beyond those related to technical standards and criteria.

Thailand identified the role of CCS as early as 2011. The government carried out R&D feasibility studies and capacity building to assess what was needed for its deployment [30]. However, the main challenges are the slow progress in terms of budget support and financial frameworks. The government also faces slow progress among the governmental agencies tasked with overseeing CCS development and increasing stakeholder engagement.

Chapter 3
CCS Policy Pillar

3.1 Current Climate Policy Landscape in ASEAN

Most of the AMS have announced national commitments to contribute to the global efforts towards emissions reduction. Based on desk research, we have learned that five countries have climate policies that include the role of CCS, and that several ASEAN documents related to carbon neutrality targets for the region mention CCS technologies. (**Table 3.1**).

Table 3.1 Summary of existing climate policies related to CCS in ASEAN

Country	Climate Policy
ASEAN	ASEAN Plan of Action for Energy Cooperation (APAEC)
	ASEAN Taxonomy Sustainable Finance Version 3
	ASEAN Strategy for Carbon Neutrality
Indonesia	An Energy Sector Roadmap to Net Zero Emissions in Indonesia
	Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) 2050
Malaysia	National Energy Transition Roadmap (NETR)
Singapore	Climate Action Plan
	Singapore Green Plan 2030
	Singapore's Long-Term Low-Emission Development Strategy 2020 /Charting the Energy Transition to 2050
Thailand	Climate Change Master Plan (CCMP) 2015-2050
	Thailand LT-LEDS
Viet Nam	Updated Nationally Determined Contribution (NDC) 2022
	Just Energy Transition Partnership Roadmap

Source: *Authors' compilation from various sources.*

The **ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021-2025** is the regional blueprint to enhance energy connectivity, accessibility, affordability and sustainability in the region [11]**.** It includes a strategy to deploy CCS/CCUS technologies to help promote the region's energy transition and a low-carbon economy. The key actions are the deployment of clean coal and CCS technologies through best practices, policy workshops, strategic reports, and high-level discussion and business dialogues in ASEAN.

The primary purpose of the **ASEAN Strategy for Carbon Neutrality** [3] is to accelerate the transition towards a low-carbon economy in the region and achieve carbon neutrality by 2050 while also promoting sustainable growth and development [5]. Identifying the potential of CCS hubs in the region (e.g., Singapore, Indonesia and Malaysia) is the first strategy to accelerate green value chain integration. The strategy also outlines ways to improve the relevant policy supports for cross-border CO_2 movement and the commercialisation of CCS technologies in ASEAN. However, to date there has been no discussion about the long-term and robust investment needed to support the economic viability of CCS technologies in the region.

Specific guidance for financing carbon capture projects is provided in the **ASEAN Taxonomy Sustainable Finance**. Version 3 of this document, which was announced in April 2024, introduces the Technical Screening Criteria (TSC) for CCUS, and offers a structured framework for assessing and classifying CCUS activities in the region [31]. This framework emphasises the role of CCUS in reducing emissions, and the need to support the transition away from fossil fuels in line with the Paris Agreement. The multi-tier approach enables transparency and accountability by providing a unified set of criteria for CCUS activities and facilitating informed decision-making and investment. However, the taxonomy relies heavily on the IEA's Net Zero Emissions Pathway for its classification of CCUS activities. It is expected that this classification may be overly ambitious for Southeast Asia and will therefore need to be modified to better reflect conditions in the region.

The regional frameworks mentioned above indicate an increasing commitment towards the role of CCS technologies in decarbonisation and that the AMS are in line with the regional commitments. Of the five AMS which have included the role of CCS in their existing climate policy documents, Singapore has the most developed roadmap for CCS deployment.

3.1.1 Indonesia

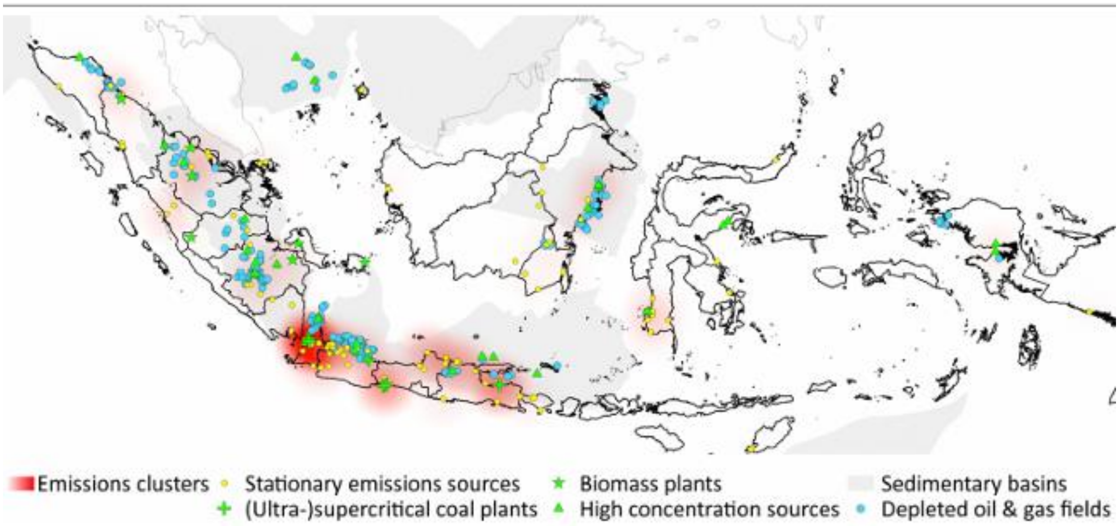
Indonesia's Enhanced Nationally Determined Contribution (ENDC) demonstrates a heightened commitment to reducing GHG emissions, with updated targets of 31.89% (unconditional) and 43.2% (conditional) reductions, compared to the previous targets of 29% and 41%, respectively [32]. In the energy sector, the updated NDC only targets a reduction in fossil fuels and an increase in the share of renewable energy to 23% by 2050. CCS technologies are not actually mentioned in the NDC.

The role of CCS in the 2050 **Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR)** is to serve as a decarbonisation technology to be deployed by the key industries with high emissions (such as fossil fuels, iron and steel, cement, etc.). The Indonesian government is targeting the use of CCS technologies in coal-fired power plants to be effective in 2030 [33]. Through the implementation of efficiency measures, the decarbonisation of power plants by mixing enormous amounts of renewable energy with coal, and employing CCS (called bioenergy with CCS, or BECCS), the total emissions from the energy sector are predicted to decrease by 458 $MtCO_2eq$ in 2050 from 1,030 $MtCO_2eq$ the 2030 level [33]. There is thought to be considerable potential for CCS at coal-fired power plants where bioenergy is mixed with the coal.

The Energy Sector Roadmap to Net Zero Emissions in Indonesia outlines measures to achieve net zero emissions NZE) in the energy sector through the use of energy efficiency with CCS deployed near the high emission industry sites, especially heavy industries such as cement, chemicals, iron, and steel, and power plants. Indonesia is fortunate to have large and well-understood storage potential in its depleted oil and gas fields. However, the distances between the emission sources and the depleted fields are large. The average distance is approximately 90 km, with 45% of the emission sources located within 50 km of depleted fields, 70% within 100 km and 93% within 200 km [34].

Moreover, Indonesia's potential CO_2 storage capacity is poorly distributed relative to the emission sources. While West Java hosts around 35% of the country's stationary emissions sources, it has only about 15% of the total storage capacity. Meanwhile, South Sumatra has more than 50% of the country's storage capacity, but around half of the country's CO_2 emissions sources fall within nine highly concentrated emissions clusters centred in East Kalimantan, Central Sumatra and Java. (**Figure 3.1**) [34]. Therefore, it may require more comprehensive site-storage assessments to identify sedimentary basins and depleted oil and gas fields in terms of practicality and cost implications.

Figure 3.1 CO_2 emission clusters and the potential for source-sink matches in Indonesia



Source: [34].

3.1.2 Malaysia

The Government of Malaysia raised its mitigation ambitions in 2022, committing to an unconditional 45% reduction in the carbon intensity against GDP by 2030 compared to the 2005 level [35]. While the updated NDC specifically cites the energy sector as one of the main sectors in which emissions can be reduced, it does not give precise targets for the energy sector. The government of Malaysia is currently completing its Long-Term Low Emissions Development Strategies (LT-LEDS) which will include a section on the power sector to complement its NDC [36].

In July 2023, the Government of Malaysia published its **National Energy Transition Roadmap (NETR)** which outlines various initiatives and strategies to transition Malaysia's energy sector from fossil fuels to cleaner energy sources. It focuses on six key energy transition levers: renewable energy, hydrogen, bioenergy, green mobility, energy efficiency and CCS. Malaysia aims to establish three CCS hubs by 2030 with a total storage capacity of up to 15 million tonnes per annum (Mtpa), with two hubs in Peninsular Malaysia and one in Sarawak [23]. The government plans to expand CCS storage capacity through developing three additional carbon capture hubs with a total storage capacity of between 40 to 80 Mtpa by 2050.

Under the NETR, the purpose of CCS in the energy sector is to expedite the country's pathway towards NZE, delivering an additional 5% reduction in GHG emissions. It also mentions the use of CCS during the production of grey hydrogen to generate blue hydrogen. Moreover, the NETR also focuses on implementing initiatives on the transboundary CO_2 development. For example, the roadmap explicitly outlines the key initiatives to enable cross-border CO_2 networks by amending the existing Exclusive Economic Zone Act 1984 (Act 311), introducing the transboundary CO_2 regulatory agreement and aligning with the established international regulations on the London Protocol (LP) and EU CCS Directive.

3.1.3 Singapore

Singapore's total GHG emissions in 2021 were 53.6 Mt CO_2-equivalent, or 0.124% of global GHG emissions [37]. In 2022, the government submitted an updated NDC which aims to reduce emissions to around 60 Mt CO_2eq in 2030 after they peak, and to achieve net zero emissions by 2050 [38]. One of the key measures that Singapore will employ to achieve its emissions target is a continuation of its shift away from oil in the power sector to natural gas (in 2021 about 95% of Singapore's total power output was generated from natural gas) [38]. Two national policies that acknowledge the role of CCS are Singapore's Climate Action Plan in 2016 and Singapore's Long-Term Low-Emissions Development Strategy (LT-LEDS) 2020 [39], [40].

The Climate Action Plan (titled "Climate Action Plan: Take Action Today for a Carbon-Efficient Singapore") outlines the country's strategies to mitigate and adapt to climate change. It calls for a reduction in GHG emissions to ensure a sustainable future for Singapore. The government also allocated SGD 55M to support research on low-carbon technologies as part of its Low Carbon Energy Research (LCER) Programme in 2021, and a further $129M to support research into hydrogen and emerging technologies such as CCUS and geothermal power generation.

Singapore's **Long-Term Low-Emissions Development Strategy 2050,** known as "Charting the Energy Transition to 2050"**,** is another climate roadmap which mentions the use of low carbon technologies, such as CCS. From an energy security perspective, CCS could allow Singapore to continue using natural gas to generate most of its electricity and soften the impact of any shortage in low-carbon hydrogen supplies – without compromising its climate change commitments.

Singapore's **Green Plan 2030** is a comprehensive roadmap outlining the nation's sustainability vision for the next decade. It focuses on addressing climate change and achieving sustainable development. CCS is highlighted as a crucial decarbonisation solution, particularly for the energy and chemical sectors [41]. The government plans to explore partnerships with companies and countries that have suitable formations for CO_2 storage. The target is to build at least 2 million tonnes of carbon capture storage on Jurong Island by 2030 and to achieve more than 6 million tonnes of carbon abatement per annum by 2050 [41].

3.1.4 Thailand

Thailand's GHG emissions equated to approximately 0.97% of global GHG emissions in 2020. Recognising the urgent need to combat climate change, the country has committed to significant reductions in its emissions as part of its NDC under the Paris Agreement. Thailand aims to cut its GHG emissions by 30% from the projected business-as-usual levels by 2030, contingent on sufficient international support [42]. The government's policies focus on enhancing energy efficiency, expanding renewable energy use and promoting sustainable transportation. Thailand has also recognised the use of CCS as reflected in its **Climate Change Master Plan (CCMP) 2015-2050** and its **Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS)**.

The Climate Change Master Plan (CCMP) involves not only the energy sector, but also the agriculture and forestry sectors. It is divided into three phases: short-term (2016), medium-term (2020) and long-term (2050) [43]. Under Strategy 2: Mitigation and Low Carbon Development, the government aims to conduct CCS feasibility studies for the power sector and to assist with the energy transition, especially for high-emission industries. Specific targets are not given.

The Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) is a comprehensive policy document aimed at reducing Thailand's GHG emissions. Revised in November 2022 after its initial submission in 2021 [44], the strategy outlines a roadmap for the country to achieve long-term carbon neutrality and net-zero targets by 2050 and 2065, respectively. The use of emerging technologies (CCS, CCUS and BECCS) in the power sector is to start in 2040 to support the 2065 net zero target.

3.1.5 Viet Nam

According to the Emissions Database for Global Atmospheric Research (EDGAR report), Viet Nam's GHG emissions in 2022 were approximately 489.16 million tons of CO_2 equivalent (Mt CO_2eq), or 0.4% of global GHG emissions [45]. Viet Nam submitted its second NDC in November 2022. This updated NDC has more ambitious mitigation targets compared to the previous one, with an unconditional target to reduce GHG emissions by 15.8% below business-as-usual levels by 2030, and with international support, a conditional target to reduce them by 43.5%. Viet Nam prioritises the use of CCS technologies and is seeking international cooperation in research and development regarding GHG emissions reduction measures [46]. However, insufficient domestic energy supplies and the high cost of low-emission technologies make it difficult for the country to tackle the situation.

Just Energy Transition Partnership, is a collaborative effort between the Vietnamese government and international partners to support the country's transition to a low-carbon economy. The partnership aims to mobilise at least USD 15.5 billion in public and private finance over the next 3-5 years to achieve Viet Nam's ambitious Net Zero 2050 goal [47]. CCS development will be focused on transitioning the Van Phong Thermal Power Plant to use biomass in combination with coal and building CCS. Efforts will also be made to develop R&D for coal energy efficiency and transfer knowledge and technology for CCS deployment [48]. The implementation of CCS technologies in Viet Nam faces significant challenges, including the need for large-scale infrastructure development and the excessive costs associated with capturing and storing CO_2. The Just Energy Transition Partnership's (JETP) focus on renewable energy and energy efficiency reflects these challenges [49].

While the climate policies of the ASEAN countries have some common features, they also have distinct differences. Thailand is focusing on evaluating the potential for CCS deployment by identifying potential barriers and determining the most suitable approaches for a particular industry or region. On the other hand, Malaysia and Indonesia provide details about target deployments and pathways to adopt the CCS integration.

In recent years Thailand has been focusing on expanding its various types of renewable energy. Hence it is still in the initial planning stages, specifically feasibility studies, for CCS deployment. Under the Climate Change Master Plan (CCMP) on the strategy number 2 of "Mitigation and Low-carbon development," the country aims to conduct CCS feasibility studies for the power sector and to develop low-carbon infrastructure to support an energy transition for the high-emission industries especially. The application of CCS, CCUS and BECCS in the power sector is to begin in 2040. The targets leave an open opportunity for further development of Thailand's CCS regulations and policies.

In Indonesia, the focus is shifting from research and planning to practical application, with attention devoted to scaling up the technology to meet the required levels for net-zero emissions. Actual adoption involves addressing the regulatory, financial and social barriers to ensure effective utilisation of CCS. Indonesia's commitment to using CCS technologies is proven under the Energy Sector Roadmap to Net Zero Emissions in Indonesia policy and the LTS-LCCR. The existence of regulatory support, geological potential and cooperation conducted by external parties such as ExxonMobil, Shell, BP and Mitsui in several CCS projects has greatly encouraged the adoption of CCS technologies in Indonesia. Although Indonesia still faces several challenges, it might achieve its CCS operational target in 2050, depending on the success of 19 existing CCS projects which are to start operating in 2030 [15].

3.2 Current CCS-related Policies in ASEAN

As described in the previous section, some of the AMS have incorporated CCS into their existing climate policies (Section 3.1). In this section, we attempt to measure the range of policy mechanisms available across the AMS to support the deployment of CCS. To analyse the key elements of the policy pillar enabling CCS deployment in ASEAN, we used the IEA Framework on CCUS Policies and Business Model Framework which was published in 2023 [28]. **Table 3.2** shows the current CCS policies of the AMS. It has five sub-pillars of enabling policies: including enabling legislation and rules, cost reduction measures, regulation of industrial activities, strategic signalling and revenue support.

Table 3.2 Summary of the policy pillars enabling CCS deployment in ASEAN

Country	Enabling legislation and rules	Cost reduction measures			Regulation of industrial activities			Strategic Signalling	Revenue Support
		Grant	Loan	Tax Incentive	Carbon Tax	Carbon Credit	ETS		
Brunei Darussalam	Not Available	Not Available	Not Available	Not Available	Considering	Considering	Considering	Not Available	Not Available
Cambodia	Not Available	Not Available	Not Available	Not Available	Not Available	Available	Not Available	Not Available	Not Available
Indonesia	Available	Not Available	Not Available	Available	In Development	Available	Available	Available	Available
Lao PDR	Not Available	Not Available	Not Available	Not Available	Not Available	Considering	Not Available	Not Available	Not Available
Malaysia	Available	Not Available	Not Available	Available	Considering	Available	Considering	Available	Available
Myanmar	Not Available	Not Available	Not Available	Not Available	Not Available	Considering	Not Available	Not Available	Not Available
Philippines*	Not Available	Not Available	Not Available	Not Available	Considering	Considering	Considering	Considering	Not Available
Singapore	Not Available	Available	Not Available	Not Available	Available	Available	Not Available	Available	Not Available
Thailand	In Development	Not Available	Not Available	Available	In Development	Available	Considering	Available	Not Available
Viet Nam	Not specified	Not Available	Not Available	Not Available	Considering	In Development	Considering	Not Available	Not Available

*Note: * It is based on the potential study.*

Legend *Not Available* | *Considering* | *In Development* | *Available*

Source: *Authors' compilation based on* [23] [50] [51] [52] [53] [54] [55] [56] [57] [58].

Indonesia leads the initial deployment and depicts a broader approach to support the deployment of projects. It has all of the key aspects of the enabling policy pillar among others. Indonesia has implemented specific regulations on CCS along with complimentary measures pertaining to financial aspects, deployment strategic plan and business models. Malaysia (currently covers only Sarawak) is the next country to move decisively on CCS to enable deep decarbonisation through a series of policies.

Indonesia and Malaysia have specific regulations on CCS, including a tax incentive to reduce the costs of CCS projects. Meanwhile, Viet Nam has only parts of the policy framework that endorsed the importance of CCS technologies. The legal basis of CCS in the Philippines and Thailand is under the oil and gas frameworks. Carbon credits to encourage investment in emissions-reduction technologies are available in most of the AMS, notably Cambodia, Indonesia, Malaysia, Singapore and Thailand. This is discussed in more detail below.

3.2.1 Cost reduction measures

To assist with the large amounts of up-front investment for CCS deployments, the AMS governments are providing grant and tax incentives. In Singapore, a USD 55 million grant has been used to fund eight feasibility study projects on CCS under the Low-Carbon Energy Research Funding Initiative (LCER-FI). However, at this point the grant still covers only research rather than upfront costs [55].

Cost reduction is a common policy mechanism in ASEAN to encourage the adoption of energy policies and new technologies including CCS. Imposing tax incentives can pay for operational expenses as well as capital costs or provide a credit value for CO_2 stored on a per-tonne basis [54]. In 2021, Thailand approved incentives in the form of eight-year corporate income tax exemptions for petrochemical production facilities implementing CCS technologies [56]. In Indonesia, the tax incentives given to CCS contractors are governed under the Presidential Regulation (PR) No. 14/2024 in accordance with the provision of laws regarding the tax treatment of Upstream Oil and Gas Business Activities (Government Regulation No. 93/2021) [53]. Malaysia approved an investment tax credit for CCS in 2023.

The cost reduction policy gaps remain wide for several countries. The tax incentives mechanism in Malaysia includes an investment tax allowance of 100% for 10 years and full import duty and sales tax exemption on the equipment from 2023 to 2027 [54]. Although tax incentives in Indonesia are ruled out under the PR No. 14/2024, details about tax incentive rates are not yet set out. The AMS must ensure that the tax incentives can attract investment, especially foreign direct investment, and that the governments do not incur any serious costs.

Another cost reduction measure that governments can take is through the involvement of state-owned enterprises (SOEs), which can indirectly reduce the costs by shifting some of the investment risk associated with the project to the public sector. Several SOEs involved in the CCS projects are Pertamina (Indonesia), Petronas (Malaysia), PTTEP (Thailand) and PetroVietnam (Viet Nam).

Table 3.3 Cost reduction policies relating to CCS projects in ASEAN

Country	Grant/Loan/Tax Incentives	Policy Gaps
Indonesia	Tax Incentive	Does not mention the rate of tax incentives specific to CCS
Malaysia	Tax Incentive	Does not mention the detailed of implementation plan
Singapore	Grant	Focuses more on research rather than infrastructure development
Thailand	Tax Incentive	Absence of legal basis to regulate the tax exemption specific for CCS projects

***Source:** Authors' compilation based on* [53] [54] [55] [56].

To accelerate the deployment of CCS projects in ASEAN, the results of our questionnaire indicate that incentives or penalties are the best ways to implement cost reduction measures. The aim is to attract investment from the private sector. The feed-in tariff scheme currently applied in the renewable energy sector could potentially be applied in CCS projects. The shared cost allocation is considered the second-best choice for cost reduction measures relating to CCS projects in the region. The aim of the second approach is the same as the first, but with more specific cost sharing between public and private investors. The third-best option is a mix of the incentive or penalty and shared cost allocation approaches. The fourth is the full control approach which aims to fully use the role of public entities with minimum involvement of the private sector (**Table 3.4.**). It is not surprising that the full control approach is not regarded as suitable for CCS projects in ASEAN due to the limited availability of public funds.

Table 3.4 Ranking of cost mitigation measures for CCS projects in ASEAN

Policy	Description	Rank
Incentive or penalty approach	Policies should aim to affect the investment decision from the private sector.	1st
Shared cost allocation approach	Policies should aim to share cost and revenue between the public and private sectors	2nd
Full control approach	Policies should aim to minimise the involvement of the private sector and fully utilise the role of public entities	3rd
A mix of above policies		4th

***Source:** Authors' compilation*

The findings from the FGDs indicated that the choice of policy approach should be adjusted or adapted according to the stages of the CCS technologies market. In the early phase of CCS project development (the first 1-5 years), an incentive or penalty framework is deemed essential to mitigate the substantial upfront capital expenditures. Thailand, however, is encountering difficulties in formulating these incentives, hindered by a lack of information on CCS costs and carbon pricing—a challenge that may be prevalent throughout the ASEAN region. The Philippines, on the other hand, advocates a renewable energy-like incentive model, such as the implementation of feed-in-tariffs for a designated duration. Finally, as the market matures, it is suggested that policy evolution towards a cost-sharing model could be beneficial, engaging the private sector more actively in the financial aspects of CCS projects.

3.2.2 Regulation of industrial activities

Several of the AMS have promoted CCS deployment through the regulation of industrial activities, such as through carbon pricing, which seeks to reduce emissions from multiple sectors. There are three general approaches to carbon pricing that are applicable in ASEAN–carbon tax, carbon credit and emissions trading systems (ETS). These are summarised in **Table 3.5** which considers a wide range of carbon pricing instruments and the policy gaps within ASEAN.

Table 3.5 AMS' Carbon pricing policies

Country	Carbon Pricing Policies			Policy Gaps
	Carbon Tax	Carbon Credit	ETS	
Brunei Darussalam	☐	☐	☐	Economic dependency on oil and gas industry may create a conflict in establishing aggressive carbon strategies
Cambodia		●		The country's interest in the voluntary carbon market is limited to forestation and agriculture
Indonesia	○	●	●	No robust methodology for the CCS-enabled carbon credits in other sector-specific carbon trading regulations.
Lao PDR		☐		Lack of environment protection law enforcement and revenue from the sale of carbon credits.
Malaysia	☐	●	☐	Insufficient nature-based projects that supply carbon credits.
Myanmar		☐		Energy consumption subsidies implicitly put a negative price on GHG emissions.
Philippines	☐	☐	☐	Expect higher electricity prices due to carbon tax implementation.
Singapore	●	●		Clear trajectory to raise carbon prices to SGD 50-80 by 2030, but unclear if this alone would prompt CCS deployment if full-chain CCS costs are higher or if additional financing mechanisms are required.
Thailand	○	●		Voluntary markets often fail to effectively reduce emissions and are prone to manipulation.
Viet Nam		○		Underdeveloped; to be fully operational in 2028.

Source: *Authors' compilation* [59].

Legend: ☐ *Considering;* ○ *In Development;* ● *Available*

Except for Cambodia and Myanmar, all of the AMS are either evaluating, creating, putting into practice, or have already put into use carbon pricing instruments (CPI). As of June 2023, the only market compliance carbon pricing instruments (CPIs) adopted by AMS are those of Indonesia's ETS, which was introduced in February 2023 and solely addresses emissions from coal-fired power stations [60]. Indonesia has several legal bases to regulate carbon pricing, including carbon credits from CCS projects. This is summarised in **Table 3.6**.

Table 3.6 Indonesia's legal bases for carbon pricing instruments

Legal/Regulation	Scope
Government Regulation No. 46/2017 on Environmental Economic Instruments	The first basis of ETS implementation for an emission and/or waste permit trading system is to be implemented by 2024.
Presidential Regulation No. 98/2021 on Economic Value of Carbon	The national framework for domestic CPIs, including carbon trading is to meet the climate targets.
Minister of Environment and Forestry Regulation No. 21/2022 on Guidelines for Carbon Economic Value Implementation	The legal basis for the implementation of a cross-sectoral ETS in Indonesia includes offsets, sector-specific carbon trade roadmaps, MRV procedures and institutional arrangements.
Minister of Energy and Mineral Resources Regulation No. 16/2022 Guidelines for Carbon Economic Value Implementation of the Power Generation Sub-sector	Serves as the legal basis for implementing the ETS for power generation, which covers a mechanism for an emissions allowance cap for power plants (PTBAE).
Law No. 7/2021 on the Harmonisation of Tax Regulations	Serves as the legal basis for a carbon tax that encompasses the implementation and subject of taxpayers on the potential of carbon tax.
OJK Regulation No. 14/2023 on Carbon Trading through Carbon Exchange	Serves as the national framework for establishing the IDX Carbon Exchange as the operator carbon market, including the principal guidelines.
Minister of Energy and Mineral Resources Regulation No. 2/2023 on the Implementation of CCS for offshore oil and gas business activities	Regulates monetisation of CCS activities through carbon credits to monetise the credits if the CO_2 is captured from outside the sector.

Source: Authors' compilation based on policy documents stated in [50] [61] [62] [63] [64] [65] [66].

Singapore launched a carbon tax in 2019 through the issuance of its Carbon Pricing Act 2018, which targets emissions from the country's largest sector emitters. In 2022, the Act was amended to introduce a new framework for international carbon credits (ICCs) to pay a carbon tax [67]. In the coming years, Thailand intends to implement a carbon tax that will apply to energy, transport and industrial operations. A study for Thailand's carbon tax is currently underway.

Four AMS—Brunei Darussalam, Malaysia, the Philippines and Viet Nam—are evaluating whether to adopt carbon taxes or an ETS. They are all presently at different phases of the assessment process. Meanwhile, all of the AMS, apart from Brunei Darussalam, continue to pursue carbon credit activities or initiatives. Myanmar has received carbon credit activities through 36 recognised projects totalling less than 500,000 tCO_2eq in emission reductions since 2004 [57]. The government of Brunei has not provided an update despite having multiple discussions with international organisations to establish the most suitable scheme for regulating carbon taxes [68].

Regardless of their approaches, carbon pricing remains a challenge for the AMS. Their dependence on fossil fuels, and the high subsidies put on fossil fuels, implicitly put a negative price on GHG emissions. Indonesia's carbon tax rate is considered one of the lowest in Asia (below Japan and Singapore). However, this has not significantly encouraged companies to call for the initiation of carbon trading. Ensuring sufficient supply from carbon credits is important. Malaysia currently has insufficient nature-based projects (only two active projects) that can supply carbon credits [69].

3.2.3 Strategic Signalling

The CCS deployment targets, in terms of the amount of CO_2 stored within a country by a certain year, are outlined in the **Table 3.7** Malaysia is the sole AMS that has clear targets on deployment projects and carbon captured capacity by a certain year as the result of a policy.

Table 3.7 Deployment target capacity in ASEAN

Country	Deployment Targets
Indonesia	• Around 6 Mt annually captured in 2030 • Around 190 Mt annually captured in 2060
Malaysia	• By 2030, three (3) CCUS hubs and up to 15 Mtpa of CO_2 storage capacity • By 2050, two (2) additional carbon capture hubs and 80 Mtpa of CO_2 storage capacity
Philippines	CO_2 emission source (candidate for CCS): • Ilijan Gas-Fired Power Plant (3.1 $MtCO_2$/y) • Sta. Rita Gas-Fired Power Plant (2.8 $MtCO_2$/y) • San Lorenza Gas-Fired Power Plant (1.4 $MtCO_2$/y) • Quezon Coal-fired Power Plant (3.1 $MtCO_2$/y) • 550 MW San Gabriel Natural Gas Power Plant (1.5 $MtCO_2$/y)
Singapore	• Around 2 Mtpa of carbon capture by 2030 • Around 6 Mtpa of carbon capture by 2050 from low-carbon solutions
Thailand	Expected CCUS contribution/target is 40 Mtpa by 2050 and 60 Mtpa by 2065

Source: *Authors' compilation based on policy documents* [23] [58] [70] [71].

Under the NETR, Malaysia has set out specific targets for CCS projects along with storage capacity targets in the short (2030), and long term (2050) [23]. Singapore has only short- and long-term plans for carbon captured in Jurong Island [70]. Meanwhile, Indonesia, the Philippines and Thailand's strategic signalling were achieved through feasibility studies on CCS potential, aligned with the net zero targets. Nonetheless, the implementation needs to be monitored with a combination of policy measures, while Thailand and the Philippines have no legal frameworks as of yet.

3.2.4 Revenue Support

Contracts-for-difference (CfD) or carbon-contracts for difference (CCfD), can contribute to an increase in a CCS project's revenue. However, this mechanism is not yet applicable for carbon capture deployment nor low-emission technology in ASEAN. Instead, Malaysia and Indonesia have used a regulated asset base model for CCS infrastructure-heavy sectors (**Table 3.8**). The regulated asset base model means that infrastructure can be owned and operated by a private enterprise, which can then charge users of the asset to recover their investment costs.

Indonesia under PR No. 14/2024 enables such monetisation opportunities in the storage activities where contractors or storage holder permits can charge the storage fees for the government [54]. Meanwhile, within Land Code 2022, the Sarawak government rules out a duty levied on carbon storage to ensure compliance for payment of storage charges/fees [51]. Nonetheless, the government has not yet set the cap prices, revenue or rates of return to prevent monopolistic behaviour.

Table 3.8 Comparison of Indonesia and Malaysia's regulated asset base model for CCS projects

Country	Legal Basis	Scope
Indonesia	PR No. 14/2024 on Implementation of Carbon Capture and Storage Activities	1) Contractors: can monetise CCS implementation by charging storage fees and/or other forms of taxation in upstream oil and gas business activities. 2) Storage holder permits: Storage fees obtained by Storage Operation Permit holders are subject to non-tax state revenues (royalties) that must be paid to the Government.
Malaysia (Sarawak)	2022 Land Code (Carbon Storage) Rules	A licensee for CCS projects must ensure that any party which enters financial or other arrangements with the storage operator or users must comply with the payment of storage charges.

Source: *Authors' compilation based on policy documents* [51] [53].

3.3 Assessment of CCS Policies' Readiness, Urgency and Influence on Economic Viability

To complement the desk research findings, a questionnaire and a closed FGD were conducted with the AMS representatives to assess each policy's maturity/readiness implementation level and the urgency of adopting CCS deployment in ASEAN.

The findings show that upfront cost incentives and performance-based incentives are two policies that are needed for CCS projects that are in the early stages or not yet in the market stage. Upfront cost incentives (grants, tax rebates and others) are considered the most influential policy affecting the economic viability of CCS projects in ASEAN. Currently, Thailand is studying the potential use of carbon pricing as one of the incentive schemes to be applied to CCS projects.

Industrial regulations and strategic signalling for investors are found to rank third and fourth. These policies are needed at the more mature level of the CCS technologies used in ASEAN. However, industrial regulations are seen as the first urgent requirement for the acceleration of CCS technologies in ASEAN. This is not surprising because only Indonesia and Malaysia (Sarawak) have the specific legal and regulatory frameworks for CCS projects (including industrial regulation). The legal and regulatory frameworks are found to be the second influence policy measure affecting the acceleration of CCS projects in ASEAN. This finding is consistent with the previous points stated in the questionnaire and desk research. Industrial regulation is essential for CCS projects, as private companies need clear guidelines on the rationale, duration and estimated something missing. Clear and well-defined industrial regulations enable a more stable business environment that reduces financial risk, establishes a level playing field and ensures the same standards and practices applicable to the relevant stakeholders.

Although strategic signalling is found to rank third in the influence level and to rank second in the maturity level of CCS projects, it is on the second rank of urgency to be implemented in ASEAN. The possible implication of this is that strategic signalling is in urgent need of implementation because it has impacts on the economic viability of CCS projects. The policy's effectiveness in signalling long-term market potential for CCS technologies encourages investors to commit resources, knowing there is a clear direction and support from the government for these initiatives.

Lastly, the performance-based incentives are found on the last rank in terms of implementation at maturity level, urgency to be adopted and influence on economic viability.

Table 3.9 Key parameters reflecting the readiness of policies' maturity, urgency and influence on CCS deployment in ASEAN

Policies	Implementation maturity level	Urgency of adoption or refinement	Influence on economic viability
Industrial regulations (e.g., emission standards, technology standards, etc.)	1st rank	1st rank	2nd rank
Strategic signalling for investors (e.g., national emission targets, etc.)	3rd rank	2nd rank	3rd rank
Upfront cost incentives (e.g., grants, tax rebates, etc.)	2nd rank	3rd rank	1st rank
Performance-based incentives (e.g., tax incentives, etc.)	4th rank	4th rank	4th rank

Source: *Authors*

3.4 Key Highlights of the CCS Policy Pillar

The AMS also exhibit varying levels of readiness and commitment towards CCS deployment in their policy pillars. The policies enabling CCS deployment include **legal frameworks**, **cost reduction measures**, **regulation of industrial activities**, **strategic signalling** and **revenue support**. In enabling CCS deployment, Indonesia and Malaysia have almost all of the required policy pillars, particularly specific legal frameworks. Though only a few of the

AMS have enabled CCS policies, all of them have launched or considered carbon pricing mechanisms, such as carbon taxes, carbon credits and ETS, that can help alleviate the high cost of the technology. Many of the AMS have also integrated strategic signalling of CCS under their net zero roadmaps.

Indonesia and Malaysia (Sarawak) lead in implementing specific **legal frameworks** and policies to support CCS projects, which include financial measures such as grants/tax incentives, monetisation and carbon pricing. The regulations related to CCS in Indonesia are MEMR Regulation No. 2/2023 on the utilisation of CCUS in oil and gas exploration, and PR Regulation No. 14/2024 on the Implementation of CCS Activities. However, the scope of Indonesia's regulations is narrow: limited to only the upstream gas and oil sector and addressing the international frameworks of the London Protocol. Meanwhile, the 2022—Land Code (Carbon Storage) Rules—covers only Sarawak and has no federal legal framework. By contrast, rather than comprehensive regulations that govern the deployment of CCS, the legal and regulatory frameworks of Viet Nam and Thailand merely call for the continuation of R&D.

In terms of **cost reduction measures**, the AMS are actively employing a mix of grants and tax incentives to alleviate the capital-intensive nature of CCS deployments. SOEs are not only involved in fiscal incentives policy. They also play a crucial role in CCS projects within ASEAN. Entities like Pertamina (Indonesia), Petronas (Malaysia), PTTEP (Thailand), and PetroVietnam (Viet Nam) are involved, potentially mitigating investment risks by shifting them to the public sector and supporting the development of infrastructure and technology. The primary goals of these financial incentives and of SOE involvement are **to reduce the costs associated with CCS projects and to attract both domestic and foreign investment.** This approach aims to make such projects economically viable and scalable in the region.

Despite these measures, challenges remain in ensuring that incentives through regulation of industrial activities effectively stimulate investment without imposing significant costs on governments. The AMS are adopting various carbon pricing mechanisms, including carbon taxes, carbon credits and ETS to incentivise emissions reduction across multiple sectors. Carbon pricing in ASEAN faces several challenges, including dependence on fossil fuel industries with high subsidies, which can implicitly devalue GHG emissions. **Addressing policy complexities, ensuring clarity and consistency, and managing fiscal impacts** are crucial for enhancing the effectiveness of these measures in accelerating the deployment of CCS infrastructure in the region.

The AMS show varying degrees of commitment through **Strategic Signalling**— (integrating CCS deployments into their national strategies). Therefore, **effective monitoring and a combination of policy measures** are essential for successful CCS deployment. The governments need to ensure that their strategic goals translate into actionable policies and regulations that facilitate project implementation and carbon capture initiatives.

Indonesia and Malaysia (Sarawak) have opted for **revenue support** through a regulated asset base model to support CCS projects in infrastructure-heavy sectors. This model allows private enterprises to own and operate infrastructure, recovering their investment costs by charging users. Moreover, **setting caps on prices, revenue and rates of return** is crucial to prevent monopolistic behaviour and ensure fair market practices. These financial mechanisms aim to enhance revenue streams for CCS projects, thereby increasing their economic viability and attractiveness to investors. By providing **a framework for cost recovery and revenue generation,** the AMS seek to stimulate investment in critical infrastructure for CCS.

Notable gaps and challenges are still present as most of the AMS are still developing their regulatory frameworks. While there are promising developments in some of the AMS regarding CCS deployment, there remains a need for more comprehensive and consistent regulatory frameworks. This involves enhanced **policy coordination among stakeholders and increased financial incentives** to accelerate the adoption of CCS technologies.

Chapter 4

The Legal and Regulatory Pillar of CCS

4.1 The Legal and Regulatory Pillar

4.1.1 Recent status of legal and regulation related to CCS in ASEAN

Among the AMS, Indonesia leads the way in regulating the implementation of CCS through several forms of legislation. It has two regulations related to CCUS, mainly governing the activities of the upstream oil and gas sector. In 2023, Indonesia's MEMR legalised the regulation for the implementation of CCUS in upstream oil and gas exploration and production activities in Regulation No. 2 of 2023 (MEMR Regulation 2/2023). This regulation outlined technical and legal requirements to ensure safe and secure CO_2 storage including its economic and business operation aspects. It discusses the implementation of CCUS to reduce GHG emissions and maintain sustainable upstream oil and gas activities [50]. This regulation is limited to only the upstream oil and gas sector. There are no clear regulations on the ownership of pore space below the surface.

Indonesia has recently announced a framework for CCS activities, called Presidential Regulation No.14 of 2024 (PR 14/2024). One section is devoted to facilitating transboundary CO_2 transportation. To complement both regulations, the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas) issued a technical regulation for Working Guideline PTK-070, which applies only to upstream oil and gas contractors as shows in **Table 4.1**. However, the regulation does not involve the SKK mechanisms needed to engage the public and build confidence in the safety of the project.

Sarawak had the first CCS-specific regulation, the Land (Carbon Storage) Rules, 2022. It was enacted within Sarawak to regulate the use of land offshore and onshore for the development of carbon storage sites. It also encompasses CO_2 storage sites and monitors its activities. The Ministry of Economy aims to present the progressive regulatory framework bill on CCS to Malaysia's Parliament by November 2024 [72]. Instead of just being applicable to Sarawak, the bill would cover the entire country.

The existing legal and regulatory CCS frameworks in Indonesia and Sarawak include the transfer mechanism for the government to address the long-term storage liabilities. The existing legislation and regulation of the oil and gas sectors in Brunei Darussalam, Philippines, Thailand and Viet Nam can be potentially applied to CCS but are not being drafted as CCS-specific [73].

Table 4.1 Summary of the existing legal and regulatory CCS frameworks in ASEAN

Country	Legal and Regulatory Framework	Year	Key points	Policy Gaps
Indonesia	MEMR Regulation No. 2 on the Implementation of CCS and CCUS for offshore oil and gas business activities	2023	Implementation of CCS and CCUS activities in the upstream oil & gas sector	Narrow scope of the upstream gas and oil sector, unclear regulations on ownership pore space
	Presidential Regulation No. 14 on Implementation of CCS Activities	2024	Cross-border transportation and the storage of CO_2 generated outside Indonesia	Does not explicitly mention a compliance to the London Protocol or consider any international implications as it regulates cross-border transport
	SKK Migas Working Guideline PTK-070-SKKIA0000/2024/S9	2024	Technical regulation on the implementation of CCS and CCUS in oil and gas work areas	The technical guideline does not cover the role of public engagement
Malaysia (Sarawak)	Land Code (Carbon Storage) Rules	2022	Regulate the use of land offshore and onshore Sarawak for storage sites	Covers only Sarawak and there is no federal legal framework to supplement this regulation
Thailand	Petroleum Act, B.E. 2514	1971	Regulates the conduct of all related petroleum business activities undertaken in Thailand,	Amendment to incorporate CCS-related activities
Viet Nam	Decision No. 896/2022/qD	2022	National Strategy on Climate Change (NSCC) for the period to 2050	These regulations are limited to the research and development initiatives. The absence of clear guidelines and implementation strategies of CCS project
	Resolution No. 55-NQ/TW	2020	Easing the regulatory framework and improving the economic structure of the energy sector	
	Decision No. 38/2020/QD-TTg	2020	Listing all the high technologies prioritised for development and investment	

Source: Authors' compilation based on [51] [52] [53] [5] [59] [60] [74] [75].

Thailand and the Philippines already have several laws and regulations that could potentially be used to regulate CCS projects. A recent public hearing in Thailand on a draft amendment to the Petroleum Act, B.E. 2514 (1971), indicates that the Department of Mineral Fuels (DMF) has been working on creating a legislative framework to support CCS-related activities [73]. The draft seeks to establish "carbon business" as an additional regulated activity that works similarly to conventional petroleum concessions. As per the CCS study, the Philippines has the option to use existing regulations, such as DOE Circular

No. 2002-08-005 and Republic Act No. 387, which serve as models for components of a CCS regulatory framework, that include exploration permits and service contracts for energy development.

Meanwhile, Viet Nam' policies and initiatives pertain only to CCS technologies. Under Decision No. 896/2022/QD-TTg on "National Strategy on Climate Change (NSCC) for the period to 2050", the government sets out research and implementation of new technologies to reduce GHG emissions in industrial processes, including CCS technologies for factories [11]. "The National Energy Development Strategy to 2030, with a Vision to 2045" within the Resolution No. 55-NQ/TW, aims to develop mechanisms and policies to recover and use CO_2 [51]. CCS technologies are listed in Viet Nam's prioritised high technologies in the category of No. 33 for development investment under Decision No. 38/2020/QD-TTg [74].

4.1.2 Legal and Regulatory Frameworks for CCS in ASEAN

To assess the details of the key points stated under the legal and regulatory frameworks for CCS in ASEAN, we believe that the 2022 IEA CCUS Handbook of Legal and Regulatory Frameworks can be made, with some adjustments, to fit the ASEAN policy context [76]. This handbook provides detailed guidance on seven key issues/elements required for all stages of the CCUS value chain (capture, transport, usage and storage) and was applied to the case of Indonesia and Sarawak. Under the existing CCS legislation and regulation of Indonesia and Sarawak, enabling first mover projects and addressing the long-term storage liabilities issues are already included in the regulations. However, key issues or elements related to international and transboundary issues are not yet captured under both existing legislations. Compared to Sarawak, Indonesia covers more complete key factors/elements related to facilitating CCS hubs. On the other hand, Sarawak's legislation already covers the classification and purification of CO_2.

Table 4.2 Existing legal and regulatory framework of CCS in Indonesia and Sarawak

Categories	Key Issues/ elements	Indonesia	Sarawak
Defining regulatory scope	Classification and purifying CO_2	X	✓
	Ownership and title of CO_2	✓	✓
Environmental reviews and permits	Environmental impact assessment	✓	✓
	Permits and authorisation	✓	✓
	Public engagement and consultation	✓	X
Enabling first mover projects	One-off legislation	✓	✓
	Preferential approaches and projects	✓	✓
Ensuring safe and secure storage	Storage resource assessment	✓	✓
	Ownership of pore space	X	X
	MRV plans	✓	✓
	Storage site inspection	✓	✓
	Operational liabilities and financial security	✓	✓
	Site closure process	✓	✓
Addressing long-term storage liabilities	Long term liability post site closure	✓	✓
	Financial assurance of long-term side stewardship	✓	✓
International and transboundary issues	Regulating cross-border CO_2 transport	✓	X
	Compliance with the London protocol	X	X
	Interaction with pressure fronts across international borders	X	X
	Overlap between multiple frameworks	X	X
Facilitating CCS hubs	Access to shared transport infrastructure	✓	X
	Facilitating shared storage infrastructure	✓	X
Other key and emerging issues	Treatment of CO_2 removal technologies	✓	X
	Interaction with other surface and subsurface resources	✓	✓
	Transitioning from CO_2 EOR (enhanced oil recovery) to dedicated storage	X	X

Legend: ✓= applicable in the regulation; X = not applicable in the regulation

Sources: [15] [50] [51] [53] [72] [73] [76] [77] [78].

A

Defining the regulatory scope

The scope of the CCS regulations includes **classification and purity of CO_2** and **ownership and title of CO_2**. First, the regulations should consider how CO_2 is classified under the existing regulations–whether it is characterised as a waste or a commodity. This is because the streams of CO_2 that have been gathered for injection and transport may contain contaminants that could corrode pipelines and well casings. Moreover, it is also important that the frameworks outline CO_2 ownership along the value chain. Determining who is accountable for any possible leakage along the process can be facilitated by a clear definition of who owns the captured CO_2 across the value chain.

Under Indonesia's existing CCS legislation, it is not clear if the CO_2 which is captured, transported or stored is excluded or included in the definitions of waste, pollutant or nuisance. The definition of "waste" in the CCS directive is not given [50], [53]. Meanwhile, in Sarawak, the injection of CO_2 into a storage reservoir is not included in the definition of waste, but the regulations mention that a CO_2 stream may include "incidental or trace substances" derived from the source or by added to the stream to improve the injection process [51].

The title of CO_2 across the value chain—captured, transported and stored—both in Indonesia and Sarawak is applicable under both countries' regulations. The contractors are responsible for any potential leakage along the way. In Indonesia, under PR 14/2024, the transboundary carbon transportation business activities are carried out by a business entity or the permit holder of a storage operation. However, the long-term site responsibility is transferred to the government [53]. The same also applies to Sarawak, where the gases are permanently stored in a storage site on state land and treated as a fixture, signifying that the Government is the absolute owner of such gases [51].

B **Environmental reviews and permitting**

The environmental reviews and permitting category consist of environmental impact assessments, permitting and authorisation, and public engagement consultation. The aim is to minimise potential leakage and enhance the safety risks of CCS projects. Sarawak and Indonesia require that **environmental impact assessments** be carried out before a storage permit is issued. The assessment includes injection site studies that consists of geological analysis, and hydrogeology processing, as well as economic, safety, environment and risk evaluation. Under the existing CCS legislation, Sarawak specifically mentions human health in their assessment. The government will revoke the storage permit if it becomes aware of any scientific finding indicating that a storage site has become unsafe or could adversely affect the environment in or around the storage site [52]. Although Indonesia does not explicitly mention human health in the assessment, there is an evaluation of the social and public engagement impacts [15].

Under the existing regulations, Indonesia and Sarawak discuss the **permitting process of CCS projects.** This involves the authorisation of CO_2 capture facilities, pipelines, site exploration for storage, and injection and storage activities. In the case of Indonesia, a CCS project is required to have an exploration permit before applying for an injection and storage permit [50], [53]. Only holders with an exploration permit can apply for an injection and storage permit, which can be granted only to business entities with a carbon transportation permit [53]. CO_2 transport authorisation in Indonesia must be approved through coordination between the MEMR and the Ministry of Maritime and Fisheries or the Ministry of Transportation. Meanwhile, applications for storage permits in Sarawak are not overseen and issued at the federal level, but instead by the Ministry for Energy and Environment within the Sarawak Government [52].

Public engagement and consultation are required by the existing CCS regulations in Indonesia. Under MEMR Regulation 2/2023, the authority is required to consult with municipal council first (the Governor of Aceh), if the work area is within the special area of Aceh [15]. Meanwhile, Sarawak does not specifically mention the need for public engagement. Instead, the Sarawak government can reject the request for permits if it decides that the licensed area is not safe or that it is not in the public interest to allow the CCS activities [51].

C

Enabling first-mover projects

Another important category (aspect) that should be included in CCS regulations is the policies that enable first-mover projects, particularly in the early stages of CCS projects. There are two key aspects: (i) one-off legislation; and (ii) preferential approaches and projects to enable and support the early stages of CCS deployment in the region.

Indonesia and Singapore signed a Letter of Intent on cross-border CCS in February 2024 after Presidential Regulation 14/2024 was officially announced in January 2024 [79]. This legislation was to complement the previous regulation—MEMR Regulation 2/2023—which does not constitute the cross-border CO_2 law. Meanwhile, Sarawak's first regulations on CCS were finalised in December 2022 after the Kasawari CCS project's announcing of the Final Investment Decision (FID) in November 2022. This full chain project is now underway off the coast of the state of Sarawak [77].

Preferential approaches and projects are another key element to provide the first mover of a CCS project with an efficient authorisations process. Early initiatives for storage development in Indonesia are reserved for the holders of current oil and petroleum leases, under a draft ministerial order [15]. The IEA notes that this can speed up storage development as the business entities holding the leases have the subsurface knowledge and comprehensive data [76]. In Sarawak, the storage facilities can be built on decommissioned or abandoned petroleum production sites. The existing regulation states the land classification for carbon storage and its requirement for each of its classification [53].

D

Ensuring safe and securing storage

To gain and sustain public acceptance of a CCS project, it is important to ensure the safety and security of geological storage. Storage development has several phases: (i) resource assessment; (ii) site development; (iii) construction; (iv) operation; and (v) closure, and post closure. The existing regulations in Indonesia and Malaysia have different conditions to ensure safe and secure storage across the CCS value chain.

The storage resource assessment in Malaysia (Sarawak) and Indonesia can be selected as a storage site only if there are no significant risks. In Malaysia, the categories of land where carbon storage is permitted are decommissioned or abandoned petroleum production sites in onshore and offshore land, deep saline aquifers, coal seams and other sites which the Authority deems suitable and safe. In Sarawak, a locality map must be certified by a licensed surveyor, along with an area plan of the potential storage site and a decommissioning plan for all structures and facilities at the site. In Malaysia (Sarawak) a locality map must be certified by a licensed surveyor, along with an area plan of the potential storage site and a decommissioning plan for all structures and facilities at the site [53]. In Indonesia, CCS contractors must have official assessments for the storage sites, including the location characteristics, and identification of potential leakage risks, groundwater contamination and geological traps, and measurement of the integrity of the buffer zone layers and impermeable zone layers [53]. Indonesian contractors can propose who carries out the storage assessment certification: an independent body, agency, institution or SKK Migas or BPMA [50]. This is to ensure the quality, credibility, reliability, completeness, accuracy and correctness of the storage site assessment, including the amount of CO_2 injected.

In neither countries' frameworks, is **the ownership of pore space** designated (including the owner of all underground geological storage formations). The legislation does not clearly state whether the rights to the subsurface, including mineral rights or pores space, are held privately or by the government.

For the **Measurement, Monitoring Reporting and MRV plans**, the existing regulations include details about the monitoring programme for CCS projects. In Malaysia (Sarawak), the CCS operators are required to submit a series of reports and information about their activities in the storage site to the relevant minister which covers the following aspects [53]:

- Condition of the storage site
- Estimated quantity and type of the scheduled gases stored
- Any incident which occurred that required corrective measures to be undertaken or implemented, and the corrective measures that were undertaken or implemented
- Any modification or changes to the storage site and the injection

In Indonesia, the contractors must submit the monitoring plan and results every six months. These consist of the CCS location characteristics and the potential risk identification (such as leaks, groundwater contamination and others). Climate change mitigation actions resulting from CCS activities are carried out through the MRV activities [73]. There are also annual routine **storage site inspections** during active CO_2 injection and post site closure. In Indonesia, an annual safety inspection by the MEMR is required to monitor the maintenance, installations and facilities in accordance with statutory provisions [50], [53]. In Sarawak, a duty officer must publish a notice requesting the storage operator to enter and inspect the storage site. A storage site permit in Malaysia (Sarawak) can be revoked if there are any leakages in the injection operations, if there is any scientific finding that makes the continued use of the storage site unsafe, or if it is adversely affecting the environment.

Both Indonesia and Malaysia have specified certain **operational liabilities and financial security status** to guarantee the availability of funds. The Sarawak government also stipulates that several documents must be produced to obtain a licence, including a locality map, prepared and certified by a licensed surveyor, an area plan of the potential storage site within the area applied for, and audited financial statements for the last two financial years preceding the date of application. Specifically for storage sites located on abandoned petroleum production sites, the contractors also must attach the proposed decommissioning plan, details of the structures and other facilities at the site, the completion schedule of the decommissioning work and the estimated date of possession of the site [51]. In the case of Indonesia, the financial requirements for a permit must at least include proof of placement of guarantees for the implementation of definite commitments to site exploration and a fiscal statement letter in accordance with the provisions of tax laws and regulations.

Both countries' frameworks have an apparent understanding of the processes for **site closure.** The Indonesian authority can only approve a site closure if the contractors meet certain conditions. For example, when the carbon storage capacity is full, the permit expires and is not extended. The permit will also be revoked if there are unsafe conditions, or a force majeure that causes closure, rendering the project no longer economical. The closure process also includes a mitigation plan against the possibility of damage to the environment and/or social disruptions. In Malaysia (Sarawak), the storage site cannot be closed until the terms of the post-closure plan are determined with the consent of the relevant authority [51].

E	**Addressing long-term storage liabilities**
	Maintaining the long-term liability is another key issue related to the storage activities regulation. This is an everlasting obligation for the stored CO_2 following the termination of injection and site closure. This liability includes post-site closure–transfer mechanisms–and financial assurances. Both can last for at least 10–20-year periods. Maintaining the storage long-term liability is an everlasting obligation for the stored CO_2 following the termination of injection and site closure. This liability includes post-site closure–transfer mechanisms–and financial assurances. Both can last for a minimum period of 10 to 20 years

Table 4.3 Comparison of the Indonesia and Malaysia (Sarawak) frameworks for CCS on long-term storage liabilities

	Indonesia	Malaysia (Sarawak)
Post-injection monitoring period	10 years	Not less than 20 years
Financial responsibility	Reserve costs for a period of 10 years after completion of the CCS activities closure	The cost of post-transfer closure depends on the Authority
Transfer of long-term stewardship	Yes	Yes

Sources: [50] [51] [53].

The **long-term post-site closure** is addressed in Malaysia and Indonesia by transferring the liability of carbon storage to the relevant authorities. In Malaysia, the Sarawak government must ensure that the closure plan meets their criteria. The authority will request the submission of a proposed post-closure plan for approval. Until the storage permit expires, even if the storage site has been closed, the operator is obliged to monitor the site and comply with its reporting and notification requirements about leakages and significant irregularities [51]. The period between the date of the storage site's closure and the storage permit' termination should be at least 20 years. The minimum duration must not be less than 20 years from the date of the storage site's closure [51]. As in Malaysia, the contractor's rights in Indonesia will end if there has been a determination of verification results after the closure plan is submitted to the authority in Indonesia. Monitoring activities are carried out when the implementation plan is approved until 10 years after completion of the site closure [72].

To finance the MRV activities relating to storage site closure, Indonesia regulates **the financial assurances of long-term site stewardship** as the special fund**.** The contractors in Indonesia are obliged to reserve costs for a period of 10 years after completion of the CCS activities closure [50]. In Malaysia, the size of the financial contribution from the storage users must be sufficient to cover the estimated post-transfer costs [51]. This is determined by the relevant authority,

A	**International and transboundary issues**
	Indonesia is the only AMS that mentions transboundary CO_2, under its existing CCS regulation (the PR 14/2024). Under this regulation, carbon transport activity in the Indonesian territory must be carried out via transportation modes with engineering standards and rules that meet the safety, occupational health and environmental protection standards. Neither Indonesia nor Malaysia is governed by the 2009 London Protocol allowing CO2 streams to be exported for CCS purposes. However, Indonesia and Malaysia are subject to the United Nations Convention on the Law of the Sea (UNCLOS). Its primary objectives include fostering peaceful oceanic utilisation, managing marine resource utilisation and advancing the preservation of marine biodiversity and environmental sustainability [78]. UNCLOS parties may use their rights in the high seas, including the freedom to establish new facilities such as cables and pipelines, and to employ any other equipment required for offshore energy extraction without obtaining permission from third parties. While UNCLOS provisions are broad, the parties are obligated to assess the environmental effects of CCS project activities on the marine environment [76]. The unavailability of guidelines for transporting CO_2 under the existing regulation could create complex legal and regulatory barriers between jurisdictions. In Indonesia, the existing PR 14/2024 mentions that the cooperation agreement serves as a guideline to issue recommendations or permits required for transboundary CO_2 [53]. Each regulation on CCS activity in Indonesia has a different scope, but currently the projects do not have significant overlap between frameworks. In Malaysia (Sarawak), the existing CCS regulation does not mention transboundary CO_2 transport.
B	**Facilitating CCS Hubs**
	Facilitating CCS hubs is a key component of the legislation and regulations required to support CCS deployment in the region. Currently, Indonesia is the only AMS that is developing a CCS hub, located in East Kalimantan [15]. To facilitate the successful development of CCS hubs, ensuring fair **access to the shared transport** and **shared storage infrastructure** is crucial. Under the PR 14/2024, Indonesia covers CO_2 access to pipelines and other modes such as ships and trucks. This is granted by the MEMR after obtaining environmental approval. Under MEMR Regulation 2/2023, the third-party technical, economic and operational safety access requirements for CO_2 operations facilities that are overseen by the contractor must be met for carbon

transport to enter the CCS hub [50]. Malaysia has no specification for open access to the shared CCS infrastructure [51].

C	**Other key emerging issues**
	In addition to the above-mentioned key issues, several other key emerging issues must be included (discussed) in the CCS legislation. First is **the treatment of CO_2 removal technologies** since most CCS frameworks do not necessarily focus on CO_2 removal technology or technology-based CO_2 removal (CDR). Several approaches to CDR include nature-based solutions, enhanced natural processes and technology-based solutions. These have been applied within Indonesia's legal frameworks that focus on using the direct air capture (DAC) technology. The next key issue is the **interaction of the CCS project with other surface and subsurface resources** that could potentially have overlapping interests (such as with seabed real estate, operator holders and existing activities in the storage site)**.** In Indonesia, the issuance of the carbon storage license area is permitted after considering the potential impact of CCS activities on the sustainability of petroleum operations in the existing drilling business permit areas. No reservoir may be used for CO_2 storage if it could impact the sustainability of petroleum operations in the current drilling area. In Malaysia, the existing CCS regulation provides general guidance for reusing the existing oil and gas assets for CCS by emphasising the government's rights to any abandoned petroleum production site and requiring the current petroleum operators to submit the decommissioning plan [51].

4.1.3 Gaps between the existing legal and regulatory frameworks for CCS in Indonesia and Malaysia (Sarawak) Cases

Indonesia's legal and regulatory framework lacks an important consideration, which is the classification and purification of CO_2. Indonesia could unintentionally categorise CO_2 as either waste, hazardous polluting material, or a commodity since the regulations do not define the meaning of waste in its CCS directive. This will affect the CCS operations since its handling will depend on the source from which itis generated or captured. The CO_2 might contain some impurities that could lead to catastrophic corrosion. Another existing gap within Indonesia's regulations is in the environmental reviews and permitting. Although Indonesia examines the environmental impacts in the site assessment, it does not specifically mention how human health could be affected at a storage site, or how the health of other organisms could be affected [50], [53].

Malaysia's regulations do mention the need to protect human health. The permitting and authorisation for a capture facility, transportation and storage are explicitly mentioned in both countries' legal and regulatory frameworks. However, where permit holders are not required to consult with communities and municipal councils first, the authorisation approach is top-down. Malaysia's regulations tend to focus on providing public notice on site permits, not public engagement. However, the authority may reject the application if the site is not safe, or if it is not in the public interest [51].

The legal and regulatory frameworks of both Indonesia and Malaysia do not set the parameters of the resource assessment process to ensure that only suitable resources are developed. There are no specific criteria on site characterisation within the regulations and what monitoring should be carried out. The frameworks state specific financial responsibility requirements to assure the availability of funds. However, it is essential that the monitoring system have access to information demonstrating the operator's financial capacity to cover any potential issues that may emerge during site operations.

The existing CCS regulations are not coherent with respect to international law preventing marine pollution (the 2009 London Protocol). However, this treaty itself has limitations and challenges. The 2009 amendment requires a two-thirds majority vote, which has not yet been achieved. Therefore, it is still not legally in effect today, but if the country ratified the amendment to the London Protocol, its application will be limited unless the Protocol is recognised by the UNCLOS.

For non-contracting parties to the London Protocol, the UNCLOS provides a broad framework for the regulation and preservation of the marine environment, which includes the seabed and subsoil, as well as their resources [78]. It establishes duties for protecting the marine environment inside the maritime borders of coastal nations or in areas outside of their national borders. However, the UNCLOS makes barely any mention of storing CO_2 by injecting it into geological formations. Meanwhile, in the European Union, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPR) became a pioneer source for CCS regulations and regional agreements under the auspices of the International Maritime Organisation (IMO) [80]. Yet, some scholars argue that fragmentation of the international laws that regulate seabed activities, such as sub-seabed CCS, reveals the need to adopt a more comprehensive set of rules about CCS before it becomes widely used around the globe.

Moreover, potential disputes may arise during the deployment of CCS, especially during the interaction with pressure fronts across international borders as well as other existing surface and subsurface resources. However, the existing CCS regulations of Indonesia and Malaysia do not provide a legal basis to prevent disputes between jurisdictions of another state or other projects [76]. To minimise the potential conflict among CCS operators and other stakeholders across borders, the establishment of essential channels of coordination and communication also needs to be discussed in the updated CCS regulations. Therefore, a mapping of all stakeholders involved across the CCS value chain in ASEAN is required to ensure a more robust and comprehensive deployment framework and roadmap for CCS in ASEAN. This is further discussed in Chapter 7.

4.2 Key Highlights of the Legal and Regulatory Pillar of CCS in ASEAN

To ensure safe and secure storage of CO_2, there are several key issues along the CCS value chain that need to be addressed within the legal frameworks, such as **(i) defining the regulatory scope; (ii) environmental reviews and permitting; (iii) enabling first-mover projects; (iv) ensuring safe and secure storage; (v) addressing long-term storage liabilities; (vi) international and transboundary issues; (vii) facilitating CCS hubs; and (viii) other key and emerging issues.**

The results of the questionnaire indicated that **the absence of a regulatory framework for CO_2 removal technology** is of first rank. This implies that having a comprehensive framework would bring multiple benefits in tackling the key challenges of a CCS project. The second rank relates to the **interactions that a CCS project has with other projects.** Overlapping must be avoided; this is related to the carbon storage assessment method used. The third rank is transitioning from CO_2 use to fully dedicated storage, and the last rank is related to **ensuring the readiness of the industry sector to use the CCS technologies**. In conclusion, the higher ranks are more related to **regulation and supply-side technologies**. The last is more related to the demand side or downstream stage of CCS technologies (industry and power) (**Table 4.4**).

Table 4.4 Challenges and emerging factors related to CCS projects

Rank	Challenges and Factors	Relation to CCS elements			
		Capture	Transport	Utilisation	Storage
Challenges based on their potential to cause bottlenecks in CCS projects					
1st	Absence of a comprehensive CCS framework	•	•	•	•
2nd	Stringent environmental reviews and permitting	•			•
3rd	Operational safety and security	•	•	•	•
4th	Need for transboundary interconnectivity		•		
Emerging factors based on their likelihood to hinder CCS projects					
1st	Absence of a regulatory framework for CO_2 removal technology (e.g., direct air capture)	•			
2nd	Interactions of CCS/CCUS projects with other projects (e.g., offshore wind and offshore CO_2 storage sites)			•	•

Rank	Challenges and Factors	Relation to CCS elements			
		Capture	Transport	Utilisation	Storage
3rd	Transitioning from CO_2 utilisation (e.g., EOR) to full dedicated storage			•	•
4th	CCS-ready requirements for prospective emissions-intensive industrial plants	•		•	

Source: *Drawn up by the authors.*

Among the AMS, Indonesia stands out as the leader in CCS legislation. It has established national legal frameworks specifically addressing CCS activities in the upstream oil and gas sector such as through the MEMR's Regulation 2/2023 and PR 14/2024. The 2022 Land Code Rules of Malaysia (Sarawak) also stand out. These regulate the use of land offshore and onshore for the development of carbon storage sites. Both countries' frameworks outline **ownership of CO_2 and the ownership responsibilities** along the value chain. This information is essential to determining responsibility in the case of leakage or other operational issues.

While Malaysia and Indonesia have developed robust regulatory frameworks for CCS projects, there are differences in how they approach **environmental reviews and permitting**. Both countries aim to ensure safety, environmental sustainability and community involvement in CCS project development and operations. Malaysia's emphasis on **human health in site assessments and the state-level management of permits in Sarawak** contrasts with Indonesia's focus on **public engagement through municipal consultations in specific regions.** In Indonesia, a sequential permitting process requires **an exploration permit** before applying for injection and storage permits. Moreover, Malaysia demonstrates a stringent approach to safety and environmental protection by **allowing the revocation of storage permits** based on new scientific findings that could compromise safety or adversely affect the environment.

Indonesia and Malaysia are actively shaping their legal and regulatory landscapes to **enable first mover projects** or **support early-stage CCS projects**. Both countries employ **preferential approaches** to support and expedite CCS deployment. Indonesia's initiative to **prioritise storage development for existing oil and petroleum lease holders leverages their subsurface knowledge and data accessibility,** potentially accelerating project timelines. Similarly, Malaysia's regulations **specify land classifications for carbon storage** and outline requirements tailored to each classification, enhancing efficiency in project authorisation processes.

The frameworks of both Indonesia and Malaysia **ensure safe and secure storage** throughout the lifecycles of CCS projects. These frameworks include **robust assessment criteria, stringent monitoring requirements and clear guidelines for financial security and site closure,** reflecting a commitment to **sustainable and responsible deployment of carbon capture technologies.** Both Indonesia and Malaysia have stringent criteria for selecting storage sites through several assessments to ensure safety and minimise risks. Neither Indonesia nor Malaysia's legislation clearly **designates ownership rights to the subsurface**, including mineral rights or pore space. This ambiguity may require **further clarification to address potential conflicts and ensure accountability in the event of issues related to storage operations.** Both countries have detailed MRV plans to monitor CCS projects effectively.

The regulations of both in Malaysia (Sarawak) and Indonesia have addressed the **long-term liability** associated with CO_2 storage sites. This includes **the requirement for ongoing monitoring and financial assurances even after the site has been closed**. The obligation to manage and monitor a CO_2 storage site extends for a minimum period of 10 to 20 years following site closure. This duration ensures continued oversight and the ability to address any post-closure issues.

Indonesia is unique among the AMS in its inclusion of **transboundary CO_2** transport within its CCS regulations. This is governed by PR 14/2024, which mandates that carbon transport into **Indonesia must adhere to strict engineering, safety, occupational health and environmental standards.** In contrast to Indonesia, the existing CCS regulations in Malaysia (Sarawak), do not include provisions for transboundary CO_2 transport. This could imply **a regulatory gap or a different approach to managing cross-border CO_2 movements compared to Indonesia.** Neither Indonesia nor Malaysia is bound by the London Protocol, which allows for the export of CO_2 streams for CCS purposes. This means both countries do not have specific international regulatory frameworks governing the cross-border movement of CO_2. The regulatory landscape on transboundary CO_2 implies both the unique approaches taken by Indonesia to meet the existing gaps under the region's regulatory framework.

There are **other key emerging issues** which need to be governed under the frameworks are **the treatment of CO_2 removal technologies and the interaction of the CCS project with other surface and subsurface resources**. Current CCS frameworks often focus primarily on CO_2 capture and storage rather than on CO_2 removal technologies. It is crucial to integrate regulations that address various CO_2 removal approaches, including nature-based solutions (e.g., reforestation), enhanced natural processes and advanced technology-based solutions such as Direct Air Capture (DAC).

The **potential overlap between CCS projects and other surface and subsurface resources**—such as seabed rights, existing petroleum operations and other subsurface activities—needs careful consideration. In Indonesia, a carbon storage license is issued for a project only after its potential impacts on ongoing petroleum operations are taken into consideration. This indicates a need for coordination between different resource management activities Malaysia's regulations similarly address the reuse of oil and gas assets for CCS, emphasising the need for a decommissioning plan and government rights to abandoned sites. Incorporating these emerging issues into CCS legislation will help address the complexities of integrating CO_2 removal technologies, managing resource interactions and ensuring regulatory coherence and environmental sustainability.

While Indonesia is advancing in establishing a CCS hub with supportive regulatory frameworks (PR 14/2024) [80], Malaysia faces challenges in specifying infrastructure access regulations to **facilitate the creation of CCS hubs**. Malaysia's current regulatory framework does not specify open access requirements for shared CCS infrastructure. This absence may hinder the development of integrated CCS hubs by potentially limiting collaboration and operational efficiency among stakeholders. **Indonesia's leadership in developing a CCS hub sets a precedent within ASEAN,** showcasing the importance of regulatory frameworks that support infrastructure development. This could encourage other countries in the region to adopt similar measures to accelerate CCS deployment and regional cooperation.

Effective coordination among **multi-stakeholders** is crucial for advancing CCS projects. Thus, **stakeholder mapping** is necessary to develop the coordination plan among the relevant stakeholders. In this report, we use Indonesia as the case study to identify the stakeholders. The key stakeholders include the MEMR, Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), Aceh Oil and Gas Management Agency (BPMA), and various ministries such as Finance and Environment. Each stakeholder plays a role in policy formulation, project approval and regulatory oversight, reflecting their degree of interest and influence across different stages of CCS deployment. Both Indonesia and Malaysia (Sarawak) currently **lack specific regulations addressing international and transboundary CCS issues.** The absence of these regulations highlights **a potential area for future development to ensure coordinated efforts among relevant stakeholders and compliance with international standards.**

Chapter 5
Storage Pillar

5.1 Current storage assessment and CO_2 storage experience in ASEAN

While storage assessment varies across the region, all ASEAN countries are currently regarded as being in the early phases of developing their CO_2 storage projects. CO_2 storage is closely related to the existence of suitable sedimentary basins which contain a range of carbon-storing geological media, such as oil and gas reservoirs, deep saline aquifers and coal seams and beds. Under this study, the storage assessment of each AMS is examined on the basis of two main types: (i) saline aquifers; and (ii) oil and gas fields. For additional information, storage assessment of coal beds is also briefly discussed.

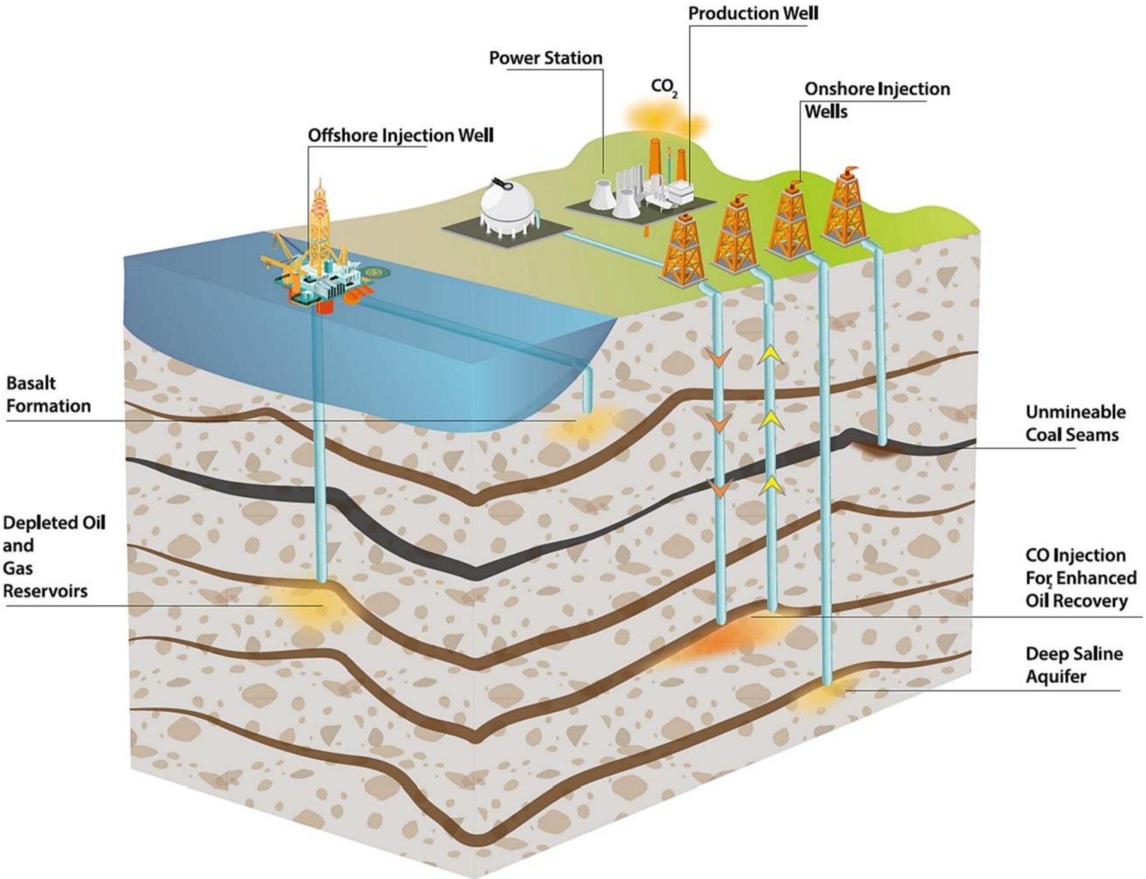


Figure 5.1 Geological CO_2 storage types
Source: [82].

- **Saline aquifers**, sometimes referred to as saline formations, are sedimentary rocks that are porous and have a large potential storage capacity for CO_2. Roughly 98% of the world's CO_2 storage resources are found in saline aquifers. However, due to a lack of site-specific data, it is unknown how much of these resources are actually usable [76]. As the data are gathered from oil and gas operations, saline aquifers close to reservoirs are better characterised than greenfield aquifers [84]. The suitable ones are usually found between 800 and 3,000 metres below the surface of the earth [85]. This ensures that CO_2 stays in a supercritical state, maximising its storage capacity and lowering the possibility of escape [86]. The geological composition of saline aquifers, such as sandstone and carbonate, allows for CO_2 injection and permeation, increasing storage capacity [84]. Saline aquifers provide CO_2 geo-storage benefits through post-injection chemical reactions like mineralisation, ensuring long-term stability and preventing leaks [84] [87]. Cap rock, or an impermeable rock layer, acts as a natural barrier preventing CO_2 from migrating upward and keeping it contained within the aquifer [88].
- **Depleted oil and gas reservoirs** offer potential for CO_2 storage due to their known geology, proven containment properties and existing infrastructure. These reservoirs, from which hydrocarbons have previously been extracted, are well-documented, with extensive data ranging from seismic to core samples detailing attributes such as rock type, porosity, permeability, cap rock integrity and fault lines [87]. Their ability to hold hydrocarbons for millions of years demonstrates their suitability for storing carbon dioxide. There are various advantages to reusing exhausted reservoirs. Typically, these reservoirs have lower reservoir pressures than their natural state due to prior extraction activities, which could make injecting CO_2 easier [76]. The abundance of current data can help reduce acquisition costs, and the large infrastructure—platforms, wells and pumping stations—may be repurposed or reused, which could lower the cost of construction and decommissioning. Nonetheless, to stop CO_2 leakage pathways, all legacy wells must be examined, and the current infrastructure must be evaluated to make sure it is still functional [76].
- **Coal beds** or unmineable coals seams, particularly those deep underground and unsuitable for mining, are ideal for storing CO_2 [89]. CO_2 molecules are adsorbed onto the coal surface in coal seams, which makes them a different kind of storage from other geological options [85]. The storage capacity of a given coal seam depends on several factors, including coal rank, quality, depth, pressure, seam thickness and surface area for adsorption [90]. Methane is naturally present in coal seams and is adsorbed into the coal structure. Due to its higher affinity, injected CO_2 displaces methane in the competition for adsorption sites [84]. This process, known as CO_2-enhanced coalbed methane production (CO_2-ECBM), offers environmental and economic benefits by providing a valuable resource. But coal seams can be poorly permeable, which complicates the injection procedure and makes tracking the movement of CO_2 difficult [91].

An assessment can be done on site. It can also be carried out at local, regional, basin or country scales. This estimate of storage capacity is subject to four different levels of certainty of capacity as mentioned below. The highest-level detail and resolution can be obtained if the assessment is conducted at the site level (see **Figure 5.2**). [92].

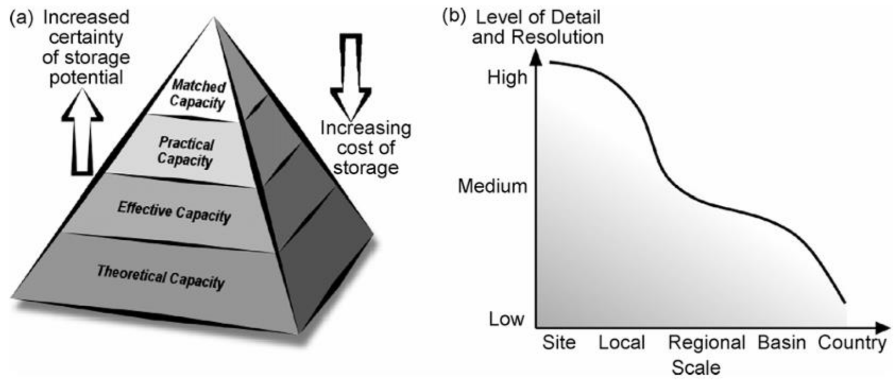


Figure 5.2 Estimation of level and scale of CO_2 storage capacities
Source: [92].

- **Theoretical capacity** is the initial approximation of geological capacity at the regional and national levels, excluding actual CO_2 filling in pores. It represents the physical limit of a system's acceptability, which can be the entire pore space or only the space from which the original resident can be displaced.
- **Effective capacity** or *Realistic Capacity* is a subset of theoretical capacity that is determined by assessing storage capacity using a variety of technical (geological and engineering) cut-off limits, considering the portion of theoretical storage capacity that is physically accessible. Typically, this estimate is updated when new information is obtained.
- **Practical capacity** or *Viable Capacity* is a subset of effective capacity that is influenced by technical, legal, regulatory, infrastructure and economic barriers. It is susceptible to rapid changes in technology, policy, regulations and economics.
- **Matched capacity** is a subset of the practical capacity produced by carefully matching large stationary CO_2 sources with geological storage locations that have sufficient injectivity, capacity and supply rate. This capacity represents the proven marketable reserves used by the mining industry.

As of now, eight AMS have estimated how much carbon dioxide they can store in the various medias. In general, the capacity of the saline aquifers is larger than the others. Storage capacity assessments of saline aquifers and oil and gas fields have reached the level of effective capacity, whereas assessments of coal beds only reach the theoretical capacity level. To date, no literature on storage assessment has been found in **Singapore** or **Lao PDR.** There also have not been any CCS demonstrations in any of the AMS. Storage capacity assessment level of each AMS is summarised in **Table 5.1**

Table 5.1 Summary of storage assessment and CCS deployment level in ASEAN

No.	Country	Storage Assessment			CO_2 storage experience
		Saline Aquifers	Oil and Gas Fields	Coal Beds	
1	Brunei Darussalam	▲ (effective)	▲ (effective)	▲ (moderately)	●
2	Cambodia	▲ (theoretical)	▲ (theoretical)	▲ (moderately)	●
3	Indonesia	▲ (effective)	▲ (effective)	▲ (theoretical)	●
4	Lao PDR	▲ (moderately)	▲ (moderately)	▲ (moderately)	●
5	Malaysia	▲ (effective)	▲ (effective)	▲ (moderately)	●
6	Myanmar	▲ (effective)	▲ (effective)	▲ (moderately)	●
7	Philippines	▲ (effective)	▲ (effective)	▲ (moderately)	●
8	Singapore	▲ (moderately)	▲ (moderately)	▲ (moderately)	●
9	Thailand	▲ (effective)	▲ (effective)	▲ (moderately)	●
10	Viet Nam	▲ (effective)	▲ (effective)	▲ (theoretical)	●

Legend:

▲ Assessed to effective capacity ▲ Assessed to theoretical capacity ▲ Moderately assessed

Source: *Authors.*

Brunei Darussalam's SW Ampa Field has 4-7 Gt of effective storage potential in saline aquifers and 0.6-0.8 Gt in oil and gas fields. The Baram Delta Basin has a total effective potential of 0.2 Gt to 0.5 Gt in saline aquifers and 0.5 Gt to 0.8 Gt in oil fields [92]. Another study estimates that the Brunei-Sabah Basin contains up to 28 Gt of CO_2 in an effective storage level [94].

A preliminary study in 2014 in **Cambodia** showed a total of 90 Mt of total storage capacity in saline aquifers and hydrocarbon reservoirs in three basins: Khmer, Kampong Saom and Tonle Sap Basins. Some 94% of the total storage is in saline aquifers [95]. This represents their theoretical capacity due to the limitation of the data.

Numerous studies have estimated **Indonesia**'s capacity to store CO_2. According to a 2013 study, one field of saline aquifers in the South Sumatra Basin has the potential to hold up to 7.7 Gt [13]. Another study conducted in 2022 revealed that the same basin had a cumulative storage potential of 13–23 Gt from all fields, compared to 32–67 Gt and 5–0.8 Gt in other basins. The study also revealed that hydrocarbon reservoirs had a storage capacity of 0.3–0.4 Gt based on calculations done at the field scale [93]. Finally, a 2024 study estimated that there were 680.57 Gt of saline aquifers in 21 basins, with oil and gas fields accounting for only 1.30 Gt out of 728 fields and 8.83 Gt from 240 fields [94].

As for **Malaysia**, the most mentioned basin is the Malay Basin, with storage potential in saline aquifers amounting to 64–138 Gt in basin-scale estimates. Other identified basins for saline aquifers are the Central Luconia Province Basin (56 Gt; basin - scale) [97], the Sabah Basin (1 – 2 Gt, field- scale) and the Sarawak Basin (0.6 – 1,4 Gt), while the total storage of oil and gas reservoirs in the Malay, Sabah and Sarawak Basins is based on an accumulation of field-scale estimates of 1.1 – 1.6 GB, 0.3 - 0.5 GB and 1.5 – 2 GB, respectively [93]. All estimates for Malaysia are estimates of effective capacity.

Myanmar is estimated to have an effective storage capacity of 3 – 7 Gt in the Moattama Basin (basin-scale) for its saline aquifers, while the total estimated fields in the basin for oil and gas reservoirs amount to 0.6 – 0.7 Gt. The other basin, the Rakhine Basin, is assessed to have a smaller capacity, i.e. 2 – 5 Gt for basin-scale saline aquifers and about 0.1Gt for its total field-scale hydrocarbon storage [93].

Estimates at the first theoretical level for the **Philippines** showed a capacity of 23 Gt for deep saline aquifers in two basins (Cagayan and Central Luzon Basins) [13], whereas gas fields have an effective capacity of 0.3 Gt. Studies in 2022 [92] estimated an efficient capacity in a different basin (Palawan Basin) of 0.4 – 0.8 Gt. Palawan basin is also estimated to have effective capacities from field-scale calculations of 1 – 3 Mt in its hydrocarbon reservoirs.

Thailand's theoretical capacity of its saline aquifers is estimated at 8.9 Gt [13]. Effective capacity estimated in other studies showed a total field-scale of 6 – 13 Gt in the Malay Basin and 2 – 5 Gt in the Pattani Basin, while the basin scales showed 16 – 35 Gt and 12 – 23 Gt, respectively [92]. Meanwhile, the first estimates of its oil fields show an effective capacity of 0.1 Gt, and of its gas fields of 1.3 Gt. A more recent study shows an effective estimate of 6 – 13 Gt for the total field-scale in the Malay Basin and 2 – 5 Gt in the overall field-scale of the Pattani Basin, while consecutive basin-scales show 16 – 35 Gt and 12 - 23 Gt.

The estimates for **Viet Nam** found capacity to be quite limited. The first theoretical estimate showed a storage potential of 10.4 Gt for the saline aquifers in the six basins, while the oil and gas fields had an effective capacity of 0.6 Gt and 0.7 Gt, respectively [13]. Other studies showed that the Nam Con Son Basin has an effective capacity of 11 – 23 Gt at the basin-scale estimate for the saline aquifer and 182 – 239 Mt effective capacity in the oil and gas zone [93].

5.2 Analysis of Key Parameters of the Storage Pillar for CCS Deployment

This sub-section provides a detailed explanation of the key parameters used in this study to assess each key factor under the storage pillar for CCS deployment framework in ASEAN. It employed the 2022 IEA CCUS Handbook on Storage Framework with a focus on only the initial stages of carbon storage [76]. The initial stages of carbon storage consist of the following key factors: (i) the identification stage which identifies storage location, capacity and its suitability for carbon storage; and (ii) the methodology used to identify carbon storage. The remaining stages are technical and socio-economic risk assessment and open access to storage data. However, it is yet too early to consider these in the AMS.

Desk research indicates that five AMS (Indonesia, Malaysia, Philippines, Thailand and Viet Nam) have completed a comprehensive identification phase for their storage facilities, including location screening, capacity estimation and storage suitability assessment. Thailand, Malaysia and Indonesia are the most studied countries due to their advanced infrastructure and data availability, making them more suitable for carbon storage studies, which require information on fields, reservoirs and hydrocarbon basins. However, a few studies on carbon storage have been carried out in other AMS, such as for Lao PDR. This is probably because some countries do not produce much oil or gas, which slows down the development of the CCS there.

Singapore is studying the viability of developing a cross-border CCS project using its industrial clusters as capture sites and storing emissions in the neighbouring countries. There is limited identification of carbon storage in Singapore. The storage in Brunei Darussalam and Myanmar is discussed at the regional level due to the unavailability of case studies. Even though storage sites have been identified, very few technical assessments have been discovered thus far. No comprehensive assessment of leakage risk for any ASEAN nation appears to have been carried out. Leakage risk is considered only when pertinent parameters are included during the identification phase. Analyses of CO_2 transportation and CCS hubs, which link carbon sources and sinks, remain likewise merely basic models or simulations. Moreover, access to data, particularly geological data, is severely constrained due to its confidentiality. The availability of access data for storage is necessary for ASEAN to map the region's CO_2 resources and potential for cross-border CCS hubs in the region.

Table 5.2 Summary of storage parameters in ASEAN

No	Country	Identification			Methodology for identification	Technical Assessment			Socio-Economic Risk Assessment		Open Access of Storage Data
		Storage location	Storage capacity	Storage suitability		Leakage risk	CO_2 transportation	CCS Hub	Social risk	Economic risk	
1	Brunei Darussalam	●	●	×	◐	×	○	×	×	×	×
2	Cambodia	●	●	●	●	○	×	×	×	×	×
3	Indonesia	●	●	●	●	○	○	○	×	×	×
4	Lao PDR	×	×	×	×	×	×	×	×	×	×
5	Malaysia	●	●	●	●	○	×	○	×	×	×
6	Myanmar	●	●	×	◐	×	×	×	×	×	×
7	Philippines	●	●	●	●	○	○	×	×	×	×
8	Singapore	×	×	×	×	×	○	○	×	×	×
9	Thailand	●	●	●	●	○	×	○	×	×	×
10	Viet Nam	●	●	●	●	○	×	×	×	×	×

Legend:

○ Preliminary ◐ Partly Done ● Done × Not Yet/Not Found

Source: *Authors.*

5.2.1 Storage identification phase

As previously stated, there are three major types of carbon storage: saline aquifers (particularly deep saline aquifers or DSF or Deep Saline Formations), oil and gas reservoirs (both depleted or DOGP/DOP/DGP and those in production decline), and coal methane beds on a smaller scale. The identification phase is the earliest phase and is usually carried out in preliminary studies of carbon storage at various scales across the three types of carbon storage. In this phase, three main steps are carried out, namely:

- Identification of **storage location** or initial screening to select the locations of fields and sedimentary basins that will be analysed further. At this stage, a small number of sites will be selected from the database based on certain parameters through ranking or elimination.
- Estimation of **storage capacity** at selected sites in terms of pore volume, limitations and other factors. This stage provides stakeholders with an important overview of potential deployments of CCS.
- **Storage suitability** assessment to select the most likely and most suitable carbon storage locations to be developed to the next stage such as initiation of pilot or demonstration projects. This stage includes consideration of infrastructure availability, site accessibility and compatibility with carbon source (capture), among other things.

Information on the methodology applied at each stage was collected from several key references and is summarised in **Table 5.3**

Table 5.3 References used for storage identification methodology

Scope of Countries	Year
Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Viet Nam [92]	2022
Cambodia [94]	2014
Indonesia [95]	2024
Indonesia, Philippines, Thailand, Viet Nam [13]	2013
Malaysia [96]	2016

Source: *Authors' compilation based on several documents* [13] [93] [95] [96] [97].

5.2.1.1 Methodology to identify the storage location

Storage assessments typically begin with the screening of databases containing lists of sedimentary basins and hydrocarbon fields in large regions, nations, or globally. To determine whether a storage location should be further evaluated, screening criteria and priority ratings based on the total weighting of the evaluation criteria are used to eliminate any listed storage potentials (**Table 5.4**).

Table 5.4 Screening criteria for saline aquifers

No.	Assessment Scale	Initial Number	Screening Criteria			Final Number
			depth	lithology	fault activity	
1.	Field-scale	62		conventional sandstone and carbonate reservoirs		42
2.	Basin-scale	128	800 - 2,500 m			96
3.	Basin-scale	N/A	> 1000 m		no active fault	N/A

***Source:** Authors' compilation based on* [13] [82] [93].

The screening criteria for the assessment of saline aquifers are straightforward, focusing on the depth of the aquifer, the type of lithology and the tectonic activity at the location. Deeper aquifers are preferred, but the number varies; one study that assessed saline aquifers in Indonesia applied a range of 800 to 2,500 meters, while another case (**Indonesia, Philippines, Thailand** and **Viet Nam**) preferred aquifers deeper than 1,000 meters [13]. This depth is critical to ensure that pressure and temperature support the injected CO_2 in a denser, supercritical stage, making it more stable, less likely to escape and requiring significantly less pore volume to store [98]. Due to their limited understanding of CO_2 storage mechanisms in fractured reservoirs, the authors of another study which assessed seven AMS (**Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand and Viet Nam**) applied lithological constraints to conventional sandstone and carbonates [93]. Saline aquifers with little or no tectonic activity, such as no active fault, are preferable due to their smaller risk of leakage.

The criteria for determining the location of oil and gas reservoirs for carbon storage are broader and more diverse. As the first considerations are accessibility and cost-effectiveness, some studies restrict their location analysis to only onshore or shallow offshore reservoirs. Some studies limit their focus to reservoir data availability for storage capacity estimates. As reservoir capacity is regarded as a crucial technical and financial feature for storage, it is also significant in the screening process. According to the references, the lower capacity limit is > 5 Mt *(specifically set to 0.5 Mt for **Philippines** due to usually smaller size)* in one study [13] and > 10 Mt (or multiple sites in *proximity* with aggregate storage of > 10 MT) in another. The minimum thickness of the reservoir and the seal are also requirements to guarantee that the CO_2 is properly trapped. This is similar to the main requirements for temperature (T) and pressure (P) to maintain CO_2 in supercritical conditions. Finally, the storage estimates for coal bed methane are based on volumetric analyses of coal beds at depths exceeding 300 metres [13].

Table 5.5 Screening criteria for oil and gas reservoirs

Initial Number	Location	Capacity	Seal Thickness	Reservoir Thickness	Activity	Injection Rate	P and T	Data Availability	Final Number
62	onshore or offshore <150 m depth	>5 Mt			onstream or have ceased production		within the required range for supercritical CO_2		38
2700									196
1083								OGIP, OOIP, EF, depth, FV, p, T	1072
N/A		> 10 Mt	> 3 m	> 3 m		> 100 t/CO_2 /day/well			N/A

Source: *Authors' compilation based on* [13] [82] [93].

The preliminary evaluation study of CO_2 geological storage in **Malaysia** and **Cambodia** is one that uses weighted evaluation criteria rather than the elimination method used in the previous tables [95][97]. The evaluation parameters used in both cases are similar and include the following: hydrogeology (aquifers), hydrocarbon potential, geothermal regime, basin depth, intensity of faulting and size of basin area. Certain other factors, like industry maturity, the basin's onshore or offshore location, and the accessibility of its infrastructure, can also be viewed as factors in determining the basin's viability or accessibility. While the study conducted in Cambodia added the parameters of evaporites and CO_2 sources, the study conducted in Malaysia added the parameters of hydrogeology, climate and reservoir seal pair. The same parameter—faulting intensity in the basin, which has a weight of 0.1—has the largest weight in both cases.

5.2.1.2 Methodology to identify storage capacity

Storage capacity assessments are usually conducted on sites that have been selected or prioritised at an earlier stage. However, capacity assessment at a regional scale is sometimes done very imprecisely as one of the assessment parameters before selecting priority sites. Most assessments conducted by the AMS use volumetric analysis with similar baseline data but vary in the additional considerations that are seen in the efficiency factors used in each study.

However, the studies to date have lacked consistency in using clear and accepted definitions of the level and scale of capacity calculations. Some studies have also lacked the use of consistent methodologies and guidelines for capacity estimations, including the lack of proper documentation of data, constraints and methodologies used.

As shown in **Table 5.6** several studies on saline aquifers used the theoretical storage capacity terminology [13, 93, and 95] , while study [13] on oil and gas reservoirs used the effective capacity terminology. Previous study uses terminology that is more familiar in petroleum reserve estimation such as contingent, probable, possible and prospective storage resources [95]. However, in the next section we examine and compare the actual parameters used by each study to see at what level the assessment was done.

Table 5.6 Stated level of storage capacity estimation of saline aquifers

Country	Scale	Stated Level
Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Viet Nam [93]	field-scale	Accessible pore volume which is a small fraction of the total **theoretical** pore space (basin-scale)
	basin-scale	Average and extrapolation of the average reservoir properties from well measurements at the limited scattered field locations across the basin to estimate the storage potential at the whole basin scale, based on regional geological models and reservoir distribution maps
Cambodia [95]	basin-scale	**Theoretical** storage capacity considering that the CO_2 is unlikely to fill an entire aquifer
Indonesia [96]	basin-scale	Contingent storage resources/proved (C1), probable (C2), and possible (C3)
Indonesia, Philippines, Thailand, Viet Nam [13]	basin-scale	**Theoretical** storage estimates for saline aquifers at the basin level
Malaysia [97]	basin-scale	**Theoretical** storage capacity determined by using the volumetric method for CO_2 capacity calculations in the deep saline formations

Source: *Authors' compilation based on* [13] [93] [95] [96] [97].

Table 5.7 Stated level of storage capacity estimation of oil and gas reservoirs

Country	Scale	Stated Level
Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Viet Nam [93]	field-scale	Volume of pore fluid replacement process where the injected CO_2 is expected to reoccupy the pore space from which the hydrocarbons were produced
Indonesia [96]	field-scale	prospective storage resources (3U)
Indonesia, Philippines, Thailand, Viet Nam [13]	field-scale	Storage estimates in oil and gas fields are assessed using actual production and reserve data and can provide detailed insights into the reservoir characteristics. Storage estimates of oil and gas fields, therefore, represent **effective** capacity.
Cambodia [95]	basin-scale	Volume based on general CO_2-Enhanced Oil Recovery (EOR) considerations thereby yielding a **theoretical** storage capacity

Source: *Authors' compilation based on* [13] [93] [95] [96].

Theoretical volumes for deep saline aquifers with structural and stratigraphic traps involve trap volume (which can be approximated by trap area and thickness), as well as porosity and irreducible water saturations [92]. To transform this volume into an effective volume, a capacity coefficient (efficient capacity) component must be added, which represents the cumulative effect of trap heterogeneity, CO_2 buoyancy and sweep efficiency. The coefficient may vary in value for each location and needs to be determined through numerical simulations and field work.

Table 5.8 shows that almost all references have included the efficiency factor as a parameter in their calculations, thus qualifying as effective capacity estimations. One study (reference used a value of 0.1 of the heterogeneity factors for **Indonesia, Philippines** and **Thailand**, and a much lower value of 0.0001 for **Viet Nam**. The study of **Cambodia** [93, 95] used about 0.02 as the overall efficiency factor. Similarly, study [96] in **Indonesia** divided the values used for clastic lithology (0.020), dolomite (0.022) and sandstone (0.015) which are valued at 50% probability of numerical distribution, which is the same as that used by the study on **Malaysia** [97]. For additional parameters, another study also included a trap geometry multiplier to reduce height and thickness into the effective average to calculate the bulk saline aquifer volume [96].

To estimate the storage capacity of oil and gas reservoirs, the approach is quite similar to that used for saline aquifers. The basic assumption that is made in storage capacity calculations is that the volume previously occupied by the produced hydrocarbons is available for CO_2 storage, with other considerations added [92]. Thus, a reservoir's theoretical mass storage capacity can be calculated based on the original gas and oil in place (OGIP and OOIP), the recovery factor, fraction of injected gas and formation volume factor. The CO_2 density is also used as another parameter to convert this mass value into volume.

The effective capacity can be determined by multiplying the theoretical capacity by the effective capacity (capacity coefficient/efficiency factor) of the reservoir. In the case of oil and gas reservoirs, it depends on mobility, buoyancy, heterogeneity, water saturation and aquifer strength [92]. This is particularly relevant in reservoirs underlain by aquifers, where changes in pressure during the hydrocarbon production process may cause water to flow into the reservoir, reducing the total pore volume that would otherwise be filled by CO_2.

Apart from the effect of the underlying aquifer, there are three other factors that control the effectiveness of the CO_2 storage process, i.e. the mobility of CO_2 relative to oil and water; the density difference between CO_2 and oil and water in the reservoir, which causes gravitational separation; and reservoir heterogeneity. All processes and reservoir characteristics that reduce the actual available volume can be expressed by a capacity coefficient to calculate the effective capacity.

Of the references gathered, only one [13] does not use OOIP/OGIP as the initial volume estimate. It uses actual production volume instead. The production volume is smaller than OOIP/OGIP, as OOIP/OGIP is the sum of production volume, remaining recoverable reserves, as well as unrecoverable oil and gas in place, thus representing estimates at the effective capacity level. As two out of three studies that used OOIP/OGIP incorporated efficiency factors (0.07 for **Cambodia**; 0.3 – 0.9 for oil fields and 0.9 – 0.95 for gas fields based on the aquifer drive at **Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam**), they were categorised as effective storage capacity as well [93], [95]. A summary of this information is given in **Table 5.9**.

Table 5.8 Parameters of capacity estimation for saline aquifers

Country	Scale	Method	Area (A)	Gross Thickness (h)	Porosity (Φ)	CO_2 Density (ρ)	Efficiency Factor (E)
Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Viet Nam [93]	field-scale	volumetric method (US-DOE)	•	•	•	•	•
	basin-scale	volumetric method (US-DOE)	•	•	•	•	•
Indonesia, Malaysia, Philippines, Thailand, Viet Nam [94]	basin-scale	Hendriks 2004; Bachu 1994	•	•	•	•	•
Cambodia [95]	basin-scale	volumetric method	•	•	•	•	•
Indonesia, Philippines, Thailand, Viet Nam [13]	basin-scale	volumetric analysis					•
Malaysia [99]	basin-scale	volumetric method (US-DOE)	•	•	•	•	•

Source: *Authors' compilation* [13] [93] [94] [95] [99].

Table 5.9 Parameters of capacity estimation for oil and gas reservoirs

Country	Scale	Method	OOIP/OGIP	Recovery Factor (RF)	Formation Volume Factor	CO_2 Density (ρ)	Efficiency Factor (E)	Production Volume	Reserve Estimate
Brunei Darussalam, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Viet Nam [93]	field-scale	Estimated Ultimate Recovery (EUR)	•	•	•	•	•	•	
Cambodia [95]	field-scale	volumetric analysis	•	•	•	•			
Indonesia, Philippines, Thailand, Viet Nam [13]	field-scale	Estimated Ultimate Recovery (EUR)			•	•		•	•
Indonesia, Malaysia, Philippines, Thailand, Viet Nam [94]	basin-scale	Bachu 2007; CSLF 2008	•	•	•	•	•		

Source: *Authors' compilation* [13] [93] [94] [95] .

5.2.1.3 Methodology to identify storage suitability

Having already screened the location, and calculated the capacity estimation, suitability is the next thing to analyse. Certain parameters may overlap with the parameters used in the screening stage, as there are different time preferences for parameter usage from the references collected. The parameters are usually used for ranking rather than for elimination. The weight assigned varies by country, according to the most important concern and the general state of the potential storage site. To create a secure and functional storage location, these parameters must meet three key requirements [99]:

- **Storage optimisation** to look for a location that has the largest storage volumes and best sealing formation so that injection can take place under ideal circumstances.
- **Risk minimisation** to reduce the impact of CO_2 migration and leakage from the storage zone. Furthermore, it will consider potential man-made (wells, etc.) and natural geological flaws (faults, tectonic setting, etc.) that could compromise the security of the storage. Matters related to technical risk assessment will be explained further in the next section.
- **Feasibility** to assess the ease of deploying CO_2 sequestration, considering factors such as storage site accessibility, public perception, economic considerations and land use for onshore sequestration.

There are at least six groups of parameters defining the suitability of saline aquifers for oil and gas reservoirs: geological-related, injection-related, monitoring and abandonment-related, and operational-related.

Geological-related

- **The capacity** consideration in this step has more to do with economics, as sites with limited capacity may not be viable for large-scale storage projects. Large sinks and long lifespans make infrastructure for CO_2 capture, transportation and injection less costly, with the AMS having a cut-off of 50 Mt or 1-11 Mt per year. Having oil and gas in one single field is also a bonus [13].
- **Confinement** refers to the capability to ensure that CO_2 remains in place. Sites with thinner seals, shallower depths, higher faulting intensity and more abandoned wells are associated with low confinement.
- In deep saline aquifers, **hydrology**, or the hydrodynamic characteristic, is essential for CO_2 injection. Shallow, short flow systems are less favourable because they do not have the residence time to immobilise the injected CO_2 by one of the other trapping mechanisms, nor do they meet the geological requirements to maintain supercritical CO_2.
- **The geothermal regime** determines if CO_2 can remain in the supercritical phase. The reservoir temperature rises while CO_2 density falls as geothermal gradients increase at the same depth. Therefore, higher geothermal gradient basins typically

have higher buoyancy forces and lower storage capacities. Cold basins have a larger storage capacity and a lower buoyancy force.

Injection-related

- High **injection rates** are preferred for effective storage in CCS projects, while low injectivity due to low reservoir quality results in high costs for injection, storage and monitoring. The Jintan (Sarawak Basin, Malaysia), Badak (Kutai Basin, Indonesia), Benchamas (Pattani Basin, Thailand), Bach Ho (Cuu Long Basin, Viet Nam) and Yadana (Moattama Basin, Myanmar) Fields are deemed suitable according to this parameter, with > 1 MTA/well [93].
- The **injection well cost** significantly impacts the project's CAPEX and OPEX, with estimates influenced by location, geological conditions and well design (specifics by geological conditions and number of wells). The availability of suitable drilling rigs and market conditions also influences estimates. Cost reductions may be applicable in large gas fields in Indonesia and Malaysia due to higher injectivity per well, requiring fewer wells overall [93].

Monitoring and Abandonment-related

- **Monitoring should** be considered to ensure safety and compliance during the project. Location, type, accessibility and infrastructure of the storage site are the determining factors and are also key in determining the monitoring cost of the project.
- **The abandonment cost** for closing and sealing wells after storage will also determine the economic viability of the project.

Operational-related

- **Availability** determines whether the storage facility can be used immediately or at the desired time to begin the pilot project. This is because some potential storage, such as that found in the Philippines, is still operational and will not become available until 2030 [13].
- Compared to reservoirs in the developing, exploration and unexplored stages, the **industry maturity** level is optimal when it is over-mature or mature. The mature industry is typically closer to the depletion date, which affects availability, and has more established infrastructure, data and understanding. Based on these reasons, the Khmer Basin in Cambodia ranked first in feasibility [95].
- **The willingness of operators** is essential for successful projects. The South Sumatera Basin in Indonesia ranked high due to the willingness of the field operator to engage with CCS, and the ongoing planning to apply for an EOR permit [13].
- **Accessibility** is evaluated by the presence and readiness of infrastructure along with transportation access to the site. The storage location has a major influence on this; onshore is preferred, then shallow offshore/near shore. However, the maturity of the

industry and public opinion may dictate that offshore sites are preferred due to land use concerns and public perceptions.

- Temperate **climates** are preferred over tropical and desert climates. Extreme weather conditions can affect the integrity of wells and make access and operations at storage sites more difficult. Basins with low surface temperatures, like those offshore and in colder regions, are preferred over onshore areas in tropical climates due to their increased capacity and decreasing buoyancy [99].

A stage called ***source-sink matching*** is required to ensure that possible storage sites can be used. This stage connects storage sites with capture sources and transport links. During this phase, the early planning process is guided towards commercial-scale, sustainable CCS projects. Moreover, this stage establishes the framework for potential commercial applications, a level after the pilot project and demonstration project. The pilot project should provide information on capture, transport and storage sinks for commercial applications, predicting future needs and benefits, and guiding the selection of a commercial project [13].

The following extra parameters are included in the methodology for identifying potential source-sink combinations: CO_2 volume, transportation, scaling, CO_2 quality and storage type.

Table 5.10 Parameters for source-sink matching on different project levels

Parameter	Pilot	Demonstration	Commercial
CO_2 volume from source	18,000 – 37,000 ton/year	183,000 – 1,000,000 ton/year	1,000,000 – 11,000,000 ton/year
Transport	Truck, boat (if pipeline still not available)	pipeline	pipeline
Scaling	Avoid capture pilot and storage pilot pairing	N/A	N/A
CO_2 quality	Pure stream of CO_2 from capture source	N/A	N/A
Storage type	Oil and gas reservoirs	N/A	N/A

Source: [13].

A study of source-sink matching in **Indonesia**'s South Sumatra Basin reveals a match between four oil fields–carbon storage less than 100 km away and a gas processing plant that supplies 0.15 Mt of carbon annually [13]. This carbon supply is more than enough for a pilot project, and if combined with additional carbon sources that are located within 150 km, it can also be scaled up to a commercial storage operation.

The source-sink matching results for the **Philippines** indicate a match between multiple storage sites in Northwest Palawan, Palawan Basin (carbon storage) and three NGCC plants in CALABARZON (a region of five provinces in the country, also known as Southern Tagalog), with a supply of 3.32 Mt/year (carbon source) [13]. Nevertheless, given the considerable 300 km distance between the two, more thought must be given to future pipelines and other forms of carbon distribution and transportation infrastructure.

The depleted offshore oil and gas fields in the Gulf of Thailand (carbon storage) and natural gas-processing facilities south and southeast of Bangkok (carbon source) were determined to be the best source-sink match for **Thailand** [13]. Despite their 200 km separation, they are linked by a gas pipeline that has the potential to be reversed and used for the transportation of CO_2. A demonstration project could benefit from the high-quality CO_2 waste stream of one of the two natural gas-processing plants used as a carbon source.

Four NGCC plants (carbon source; emission hubs) and eight offshore fields in southern **Viet Nam**'s Cuu Long Basin make up the proposed source-sink matching pilot project (carbon storage) there [13]. Less than 150 km separates the two. The pair, built as a demonstration project, will facilitate long-term planning for CO_2 sources and storage locations in South Viet Nam and the Cuu Long Basin, potentially enabling the construction of a CO_2 backbone pipeline in Central Viet Nam.

Occasionally, viability and cost-effectiveness become more obvious when we consider the concentration of carbon sources and storage locations over a greater area, such as the ASEAN region. A system called a CCS hub is created by the possibility of distributing current sources and storage and create shared infrastructure. The following section covers this topic in greater detail.

5.2.2 Technical assessment phase

5.2.2.1 Leakage risk

In the process of storing carbon, injections of CO_2 into deep geological formations may cause wells, cap rock, geological faults and fractures to leak CO_2. Such leakage could make it possible for CO_2 to enter the atmosphere or move into shallow geological formations, contaminating the air, rivers, lakes, soil and shallow subterranean water. This could harm the ecosystem and pose health risks [100].

CO_2 leakage from storage sites is significant in CCS projects, especially when a reservoir or field is injected for the first time [101]. Insufficient data and complex geology contribute to this issue, making it difficult to understand its effects. The AMS, lacking extensive experience in developing CCS projects, should be particularly concerned about this risk.

A risk management or an assessment guideline is necessary to guarantee that CO_2 leakage can be minimised both during and after injection, given the complexity of geological storage sites. The process of finding, analysing and assessing potential risks is known as risk assessment. This may require some simulation, modelling and ground checking to identify the magnitude and possible path of the leakage. Following the completion of the risk assessment, risk management procedures including monitoring, emergency response and remediation should be implemented [102].

Regretfully, for none of the AMS, a thorough risk assessment or risk management strategy has been presented. Some studies in several AMS (**Cambodia, Indonesia, Malaysia, Philippines, Thailand** and **Viet Nam**) have considered only the factors that are integrated into the screening and suitability ranking stages. This increases the vulnerability of storage sites to leaks [96] [99]. Details about the parameters are explained below.

- **Tectonic setting:** Oceanic convergent basins are less favourable due to their location in tectonically active regions which require more effort to manage due to higher leakage risks, seismic susceptibility, and potential CO_2 catastrophic escape or leakage into the atmosphere.
- **Faulting intensity:** The degree of potential leakage and of catastrophic escape of CO_2 to the surface is reflected in the faulting intensity. Extensively faulted and fractured sites are excluded from consideration.
- **Basin depth:** CO_2 injected at depths below 800 meters may be stored in the gaseous phase, occupying larger pore space volumes than in the dense phase, thus increasing the likelihood of highly buoyant CO_2 leaking to the surface.
- **Confinement/sealing capacity:** Factors like capillary sealing pressure, lateral continuity, thickness (studies prefer > 3 m), ductile/brittle behaviour and fractures influence cap rock CO_2 confinement. Strong reservoir seal pairs improve long-term hydrocarbon resource retention.
- **Number and type of well:** When it comes to CO_2 storage sites, the weak cement sheath behind the casing in abandoned wells is known to be the most likely leakage path. The well-to-well crossflow in areas with a high concentration of wells can also lead to higher leakage rates.

Indonesia's Presidential Regulation No.14/2024 also emphasises the need for CO_2 measurement within each CCS chain using calibrated measurement devices. It also states that if the leakage occurs during transportation across the Indonesian border, it shall not be included in Indonesia's GHG inventory [103].

5.2.2.2 CO_2 transportation

CO_2 transportation is necessary to link the carbon sink and carbon source. Pipelines are typically used for long-distance transportation of large quantities of gas phase carbon dioxide. Meanwhile, ships or marine tankers are typically used to transport $CO_2$when it is liquefied [104]. While transporting CO_2 is comparable to transporting other liquefied petroleum gases, there are certain prerequisites and technical specifications that must be fulfilled. The tank truck and rail options cost more than twice as much as a pipeline. As with source-sink matching, pure stream sources should ideally supply the CO_2 being transported.

Transportation by pipeline

To prevent corrosion and hydrate formation, CO_2 should be transported dry, with no free water. According to field experience in other countries, dry carbon dioxide does not corrode carbon-manganese steels used for pipelines, so long as the relative humidity is less than 60%. Transporting wet CO_2 in low-alloy carbon steel pipelines is not feasible due to high corrosion rates. If CO_2 cannot be dried, stainless steel may be used, but steel has become more expensive, making this not the most cost-effective option [104].

Furthermore, CO_2 needs to be transported at high pressure. These conditions not only meet the requirements at the CO_2 injection stage but are also less expensive. To prevent two-phase flow, the intermediate pressure range of 4.8 to 9.6 MPa is avoided [104].

Ship transport

Ship transportation requires a full marine transportation system, which includes facilities for loading and temporary storage. The transport of CO_2 by ship is comparable to that of liquefied petroleum gas (LPG). At the delivery point, the CO_2 is unloaded into temporary tanks if it is offshore, or straight into a storage system if it is onshore, onto a platform, floating storage facility or single-buoy mooring [104].

CO_2 is delivered to clients via tanker trucks or pressurised cylinders once it has reached the distribution terminals. However, there is still a very limited amount of general ship transportation for CO_2 in the world, even when it comes to customer-facing designs.

There are three types of tank structures on liquid gas transport ships: low temperature, pressure and semi-refrigerated. Low temperature types maintain liquids under atmospheric pressure, making them ideal for mass transit, while pressure types stop gas from boiling. The semi-refrigerated type takes cargo gas pressure and temperature into account [104].

A CO_2 cargo tank must be pressure-type or semi-refrigerated since liquid CO_2 requires low temperatures and pressures above atmospheric pressure. Semi-refrigerated tanks, with design points of approximately -54°C per 6 bar to -50°C per 7 bar, are preferred by ship designers [104].

Transportation scenario for the AMS

To date, there has been no comprehensive study or plan on carbon transportation to support carbon storage in ASEAN. However, several studies have analysed possible transportation scenarios, both domestically and cross-border within the ASEAN region.

One study developed a scenario for the transportation of CO_2 based on the assumption that the carbon supply originates from **Singapore's** industrial operations and total power generation and is exported from a single port terminal on Jurong Island. Through a point-to-point network, this carbon source is linked to multiple potential carbon sinks in nearby nations, including one in Fairley, **Brunei Darussalam** (offshore) and South Sumatra, **Indonesia** (onshore) [93].

The result shows pipeline transport is often preferred for closer sinks, while a ship is a more cost-effective way to transport CO_2 to offshore sinks farther than 1,100 km away. The costs of moving and storing CO_2 from Singapore to regional storage options are generally well within the range that would enable CCS to make a major contribution to ASEAN's efforts to reduce CO_2 emissions.

Another study [13] for **Indonesia** stated that one of Indonesia's potential basins, the South Sumatra Basin, already has existing pipeline infrastructure which could be leveraged for CCS transport. The area has a relatively low population density, which lessens any risk of impacts from the pipeline construction. In the **Philippines,** it has been suggested that an existing 504 km natural gas pipeline could be used to transport CO_2 between its source-sink match – CALABARZON – and an offshore gas field storage site. However, a detailed assessment of this has not been carried out.

5.2.2.3 CCS hub

Regarding carbon storage, the most pressing issue is the **mapping of potential CO_2 sources and sinks**. In particular, the significance of the proximity of CO_2 sources to sinks significantly determines commercial viability, given that the geographical distance influences transportation costs. The lack of an integrated database for these identified potential storage sites likely contributes to the urgency of their ranking. Identification is typically conducted alongside general storage characterisation and is followed by a detailed assessment of the most promising basins. Nonetheless, the characterisation of CCS resources is considered the third most urgent concern.

The commercial viability of CCS storage is viewed as the second most critical issue. This perception may stem from the necessity to ensure that identified and characterised storage site projects are selected on the basis of their commercial feasibility. In some cases, the long-term economic feasibility of CCS storage is regarded as the top priority. Hence, assessing the cost-effectiveness of various storage options and the creation of financial models to support this evaluation are critical.

Access to storage facilities ranked first, followed by access to transport infrastructure and utilisation sites. This is due to the strategic importance of the destination for CO_2, the potential for economies of scale, and the operational efficiency it provides. Storage accessibility directly influences the commercial viability of CCS projects and is essential for risk management. By contrast, while **transport infrastructure and utilisation sites** are important, they are secondary to the immediate need for secure and adequate storage solutions that ensure the success and sustainability of CCS initiatives in the region.

After the capture stage, CO_2 can either be stored in geological formations or used in various applications. The findings show that for geological CO_2 storage, the most important factor is the **establishment of proper standards for storage sites**, ensuring safety and regulatory compliance. The second most critical factor is financial assurance for long-term stewardship, which guarantees that resources are available for ongoing monitoring and maintenance. The third most important factor is the transfer of responsibility following site closure, ensuring that there is a clear and accountable process for managing the site post-closure (**Table 5.11**).

Table 5.11 Ranking of the importance of factors pertaining to the role of CO_2 storage and use

Rank	Geological CO_2 storage
1^{st}	Proper standards for storage site
2^{nd}	Financial assurance of long-term stewardship
3^{rd}	Transfer of utility following site closure

Source: *Authors.*

Multiple carbon sources can be connected to multiple carbon storage sites using shared transportation and infrastructure through a concept known as a CCS hub and cluster network [104]. Several small-scale carbon sources can be grouped into capture clusters to make it more economical. There can also be "storage clusters", where CO_2 is distributed among a group of close geological storage locations. Collection hubs will form a connective element among a constellation of capture sources (clusters). Then, collection and storage hubs will provide point-to-point transportation for compressed CO_2.

Figure 5.3 A CO_2 transport network connecting a capture cluster, capture hub and storage hub
Source: [105].

There are at least four advantages to scaling up CCS via clusters and hubs, which are also the fundamental components of a successful commercial mode for CCS [106]. Hubs and clusters will also help to effectively meet countries' national CO_2 reduction targets.

- **Cost sharing:** Through cost sharing, storage sites can be connected to low-cost industrial sources, helping participants cut early infrastructure costs. Sharing infrastructure can also reduce operating and investment costs. This can lower the entry barriers for participating CCS projects by reducing the cost per unit of CO_2 transported.
- **Stable operation:** CO_2 emission sources and sinks may not match perfectly. The mismatch between their locations renders scaling up CCS difficult. With the cluster and hub, this mismatch could be effectively corrected, ensuring that enough stable CO_2 is available for CCS projects.
- **Favourable policy:** The hub's cluster may reduce both the negative effects on communities and the environmental problems that accompany the development of infrastructure. Additionally, it might reduce and simplify the work involved in obtaining regulatory and planning approvals, negotiating with landowners and holding public consultations.
- **Beneficial commercial mode:** The cluster or hub could connect all participants involved in capture, transportation, use and storage, allowing cooperation and resource use, such as heat from industrial clusters' capture operations, and sharing benefits and risks.

Southeast Asia's size and its gas and oil infrastructure near favourable geological locations make it an ideal location for developing a CCS hub for CO_2 storage solutions [7]. With strong technical capabilities, ASEAN has the potential to become a major offshore operations provider of CCS services. The ASEAN Memorandum of Understanding on the Trans-ASEAN Gas Pipeline (TAGP) may provide lessons learned for future CO_2 pipeline networks, demonstrating the region's potential for growth in offshore operations.

Two different studies in 2022 recommended cross-boundary CCS hub and network schemes for the ASEAN region. In both, Singapore was used as the starting point for carbon capture which is then transported to several sinks in neighbouring countries. In the first study, the basins that became storage sites were Minas Basin (receiving carbon from Sumatra and Singapore clusters), Arun Basin (receiving carbon from Sumatra and Singapore clusters), and storage clusters in Malaysia (receiving carbon from Malaysia and Singapore clusters) (illustrated in **Figure 5.3**).

In the second study, storage sites that receive carbon from clusters in Singapore are spread across Indonesia, Malaysia, Brunei Darussalam, and Thailand, Myanmar and Viet Nam (illustrated in **Figure 5.4**). Singapore was chosen as the main capture cluster or capture hub because it has many carbon-emitting industries, but not enough storage capacity.

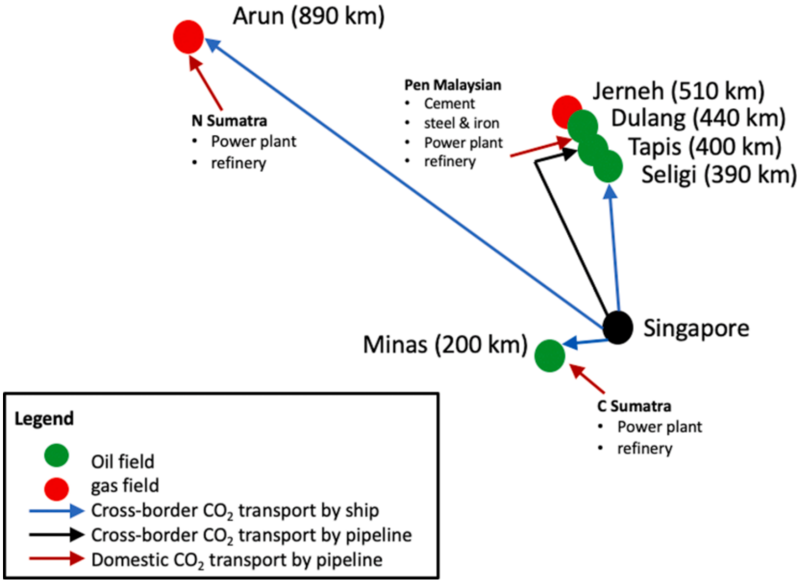


Figure 5.4 ASEAN CCS Hub & Network (1)
Source: [107].

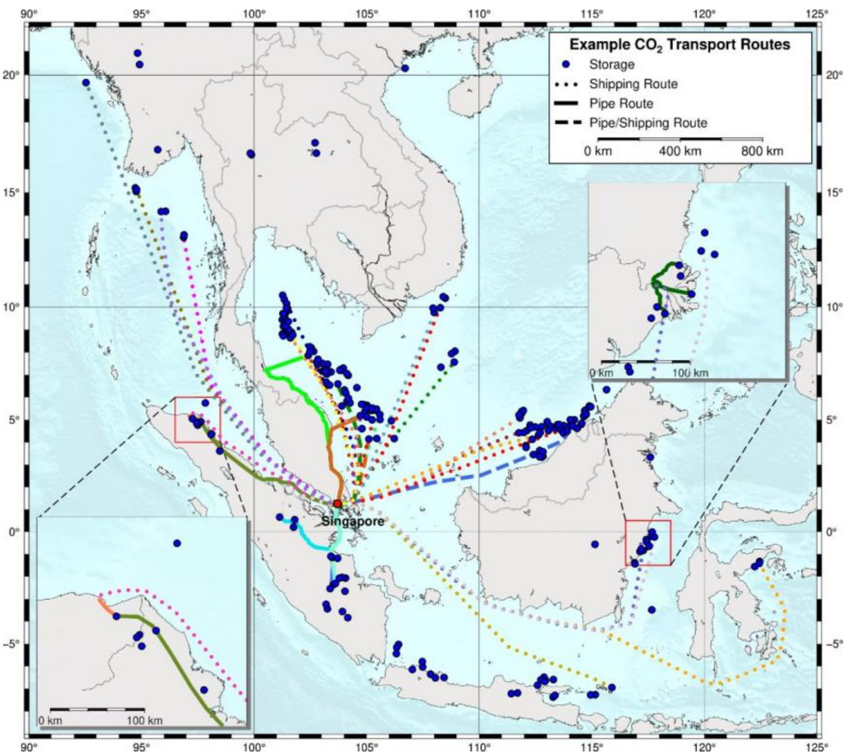


Figure 5.5 ASEAN CCS Hub and Network (2)
Source: [93].

In a conference attended by the Asia CCUS Network, National Research and Innovation Agency of Indonesia and MEMR of Indonesia, **Indonesia** is mentioned as one of the countries in ASEAN to emerge as a regional CCS hub, supported by the country's significant potential in both deep saline aquifers and hydrocarbon fields, and backed up by excellent research [108]. Indonesia is also ranked the highest in Asia in terms of a CCS regulatory framework. Several state and private companies have also started CCS Hub projects in

Indonesia, such as Pertamina, Mitsui, Chevron, and ExxonMobil in the Central Sumatra Basin, Kutai Basin, and Asri Saline Formation.

Malaysia's Ministry of Economy is also pushing bilateral agreements aimed at positioning Malaysia as a regional CCS hub [109]. A standalone CCUS Bill will be introduced by the end of 2024. The country's National Energy Transition Roadmap (NETR) also aims to develop three CCUS hubs by 2030, with one planned for 2040 and three by 2050 [110]. Key initiatives in the NETR include funding for CCUS hub infrastructure development, carbon storage agreements, liability and cost sharing in transboundary CO_2.

Malaysia's Sarawak CCS Rules regulate carbon storage licence and permit applications in Sarawak, allowing Petronas to establish carbon storage hubs [110]. Petronas plans to develop three clusters: northern, southern and eastern, with interconnection via export pipelines for transporting CO_2 to storage sites. Each cluster will receive foreign CO_2 transported by LCO_2 carriers to their terminals. TotalEnergies and Mitsui are also supporting the development of CCS hubs in Malaysia [111].

PTTEP and DMF head the Thailand CCUS hub project in Eastern **Thailand** [110], [112]. Emissions from PTT's various facilities, such as power plants, refineries, petrochemical plants and natural gas processing plants, will be addressed in the first phase of this initiative. According to the initial projections, the annual emissions targeted for CCS by 2030 may exceed 6 Mt of CO_2. There has been a preliminary evaluation of the targeted geological formation's potential for storing carbon. The early and preliminary front-end engineering design (FEED) for the development plan of storage drilling and supporting infrastructure has been completed, and the project is anticipated to begin its execution phase in 2026.

As for **Singapore,** an S-Hub consortium involving ExxonMobil and Shell was established to assess and advance a cross-border CCS project [113]. This consortium and the Singapore Economic Development Board (EDB) inked an MoU in 2024 to coordinate the planning and development of a CCS project that is expected to be deep underground or under the seabed and capable of capturing and permanently storing at least 2.5 Mt of CO_2 annually by 2030. Storage locations will be chosen following a thorough evaluation to ensure their suitability.

5.2.3 Socio-economic risk assessment phase

CCS is a new mechanism with complex technical and impact implications. As CCS technologies advance, certain environmental risks as well as economic and social issues are becoming more apparent. However, there are currently very few studies available that address risk assessment [114]. Assessing risk performance is crucial when developing CCS projects so that decisions about project sustainability can be made.

The development of CCS projects will involve numerous stakeholders [114]. Risks related to the economy can impact businesses, actors in the region, energy companies, and oil and gas companies. In the meantime, interest groups, the media and the general public may be impacted by social risks.

Some of the economic risks related to the sustainability of CCS projects include [114], [115]:

- **Cost:** usually broken down into three categories: capture, transport and storage. More specifically, it can be broken down into several categories such as affordability, unit capture cost, payback period uncertainty, operation and maintenance costs, and additional operation costs in demonstration projects. Uncertainties like fluctuating carbon prices, costs and policy changes can also impact the value of CCS projects, which frequently lack business support. There are also very few viable business models for CCS.
- **Market:** market barriers, market uncertainties, market competition, and market maturity.
- **Industrial development:** affected by the development of the capture, transportation, utilisation and monitoring industry.

Meanwhile, the social risks of CCS projects include:

- **Understanding and acceptance** by the public, stakeholders, experts, and the government and authorities. This also includes some perceptions, such as perceived health impacts.
- **Equality and Equity** between regions and generations, including the availability, accessibility, management and the negative impacts.
- Project cancellation may result from ignoring these risks. For the AMS, however, no comprehensive risk assessment has been carried out. In addition to the technological risks covered in the preceding section, it is imperative to consider the economic and social risks.

Project cancellation may result from ignoring these risks. For the AMS, however, no comprehensive risk assessment has been carried out. In addition to the technological risks covered in the preceding section, it is imperative to consider the economic and social risks.

5.2.4 Access to storage data

Geological data are needed at every stage of the development of CCS projects. According to the survey questionnaire given to the AMS, the most pressing issue for storage and technical CCS development is the mapping of potential CO_2 sources and sinks.

To properly carry out the storage identification, technical assessment and socioeconomic assessment stages, this data is essential. Depending on the available data, characterising and evaluating CO_2 storage can be a difficult task.

To create an atlas of CO_2 storage resources, pre-commercial CO_2 storage assessments must be carried out by government organisations and the agencies in charge of mineral and petroleum resources [11]. Southeast ASEAN oil and gas companies are expected to be significant collaborators due to their existing wealth of data, particularly regarding depleted oil and gas reservoirs. To support cross-border CCS hub projects, information sharing between oil companies and the national geological survey authorities is essential.

Currently, there is no catalogue that compiles the original geological data or the assessment results from carbon storage studies conducted in ASEAN It would be very good if ASEAN could create its own resource catalogue. Not only would it be helpful for future research on CCS in the region, but it would also provide transparency and assurance for nations, stakeholders and industries to begin cross-border projects.

5.3 Key Highlights of the CCS Storage Pillar

All of the AMS are still in the early stages of developing their CO_2 storage projects. They have all stated that significant advancements are needed to progress to more mature technologies in storage. The CO_2 storage potential is primarily evaluated in three geological media: saline aquifers, depleted oil and gas reservoirs and coal beds. Moreover, the CO_2 storage capacity assessment levels vary by **theoretical, effective, practical and matched capacity.** The AMS have conducted estimates of their CO_2 storage capacities across different geological media. **The "effective capacity"** level has been reached in eight AMS, meaning that these estimates are based on detailed geological and technical data.

Moreover, this study also analyses key parameters of the storage pillar, which includes the **storage identification phase, technical assessment phase, socio-economic risk assessment phase and open access of storage data**. Six AMS–Cambodia, Indonesia, Malaysia, the Philippines, Thailand and Viet Nam–have completed thorough **identification phases**. These countries have conducted **location screening, capacity estimation and suitability assessments for potential storage sites.** Thailand, Malaysia and Indonesia are highlighted as the most studied nations due to their advanced infrastructure and rich data resources. This makes them more suitable for detailed carbon storage studies, as they possess extensive information on fields, reservoirs and hydrocarbon basins.

The **identification phase** for carbon storage is a crucial initial step in evaluating potential storage sites for CCS projects. This phase involves a structured approach to selecting and assessing potential locations for carbon storage in accordance with the deeper aquifers' methodology. While a study evaluating salty aquifers in Indonesia applied a range of 800 to 2,500 metres, another case (Indonesia, Philippines, Thailand and Viet Nam) prefers aquifers deeper than 1,000 meters.

To **identify storage capacity**, assessments conducted by the AMS typically use volumetric analysis with similar baseline data. However, there is variability in how efficiency factors are incorporated, leading to differences in study outcomes. Parameters used to assess **the suitability of storage sites** often overlap with those used during the screening stage. There are three essential requirements for a site to be deemed suitable for CO_2 storage: **storage optimisation, risk minimisation and feasibility**. However, the potential and suitable storage sites may be distributed unevenly, with some countries having more favourable conditions than others. In this context, **the creation of CCS hubs and shared infrastructure** becomes crucial. By connecting countries within a larger region, such as ASEAN, these hubs allow for mutual benefit from CCS technologies. They enhance viability and cost-effectiveness by leveraging concentrated carbon sources and storage locations.

Moreover, **the technical assessment** is also a crucial point to evaluate potential storage projects, encompassing leakage risk, CO_2 transportation and CCS hubs. Currently, the AMS have yet to develop thorough risk assessments or management strategies for CO_2 leakage. The existing studies address mainly factors relevant to screening and suitability rather than detailed risk evaluation. **Leveraging existing infrastructure and optimising transportation methods** are key to making CCS viable.

While CCS technologies are promising, they bring complex **socio-economic risks**, which include cost, market, industrial development, public acceptance, equality and equity. As the technologies evolve, **understanding and addressing these emerging risks** are crucial for the successful implementation and sustainability of such projects. **Effective risk assessment** is essential for CCS projects to ensure their viability and sustainability. Despite its importance, there is currently a lack of comprehensive studies focused on risk assessment. **Addressing both technological and socio-economic risks** is crucial for developing effective and sustainable CCS projects.

Lastly, open access of storage/geological data is also crucial throughout all phases of CCS project development, including storage identification, technical assessment and socioeconomic evaluation. The availability and quality of this data significantly impact the effectiveness and accuracy of CO_2 storage characterisation. In ASEAN, **oil and gas companies, with their extensive data on depleted reservoirs,** are expected to play a key role in CCS projects. **Effective collaboration and information sharing** between these companies and national geological survey authorities are essential for the success of cross-border CCS hub projects. **Establishing a resource catalogue in ASEAN** would not only facilitate future research but also provide reassurance to nations, stakeholders and industries. It would also support **the initiation and development of cross-border CCS projects** by making critical data more accessible and transparent.

Chapter 6

Key Challenges to CCS Deployment in ASEAN

This study analyses the key challenges facing CCS deployment in ASEAN based on the 2023 IEA CCUS Policies and Business Models Handbook which divided the key challenges for the commercialisation into four main categories: (i) economic viability; (ii) long lead times; (iii) project complexity; and (iv) innovation gaps [28]. A questionnaire was given to the AMS representatives during a closed FGD which asked them to rank each of the key sub-parameters related to the common CCS challenges. The findings are given in **Table 6.1**.

Table 6.1 Common challenges in CCS development and implementation

No	Common Challenges	Impact	Urgency
1.	Economic viability (including financing availability)	1st rank	1st rank
2.	Innovation Gaps	2nd rank	2nd rank
3.	Project design (including long lead times and project complexity)	3rd rank	3rd rank

Source: *Authors.*

The following sub-chapters closely examine the identified challenges, from the most to the least.

6.1 Economic viability

The AMS representatives deemed that the economic viability of CCS was the most serious challenge facing the deployment of CCS technologies in the region. Not only are the CCS technologies expensive, but a robust carbon pricing instrument is needed to ensure a level of playing field. Economic viability in the context of CCS relates to the specifics of the carbon pricing instrument in relation to enabling the unabated facilities that would pose a challenge to the investment climate and the competitiveness of low-emission technology which would capture high-cost but low-emission energy as the outcome product [28].

The price of carbon in the ASEAN region does not exceed USD 50/tCO_2 [116]. The business model environment needs to be improved. At present, the financial burden of CCS development falls entirely on the government. Investors are needed to share the costs. [117]. The scalability and cost intensity of use make it difficult to reach a wider uptake of CCS in the region. The economies of several AMS are still recovering from the COVID pandemic. Hence consideration of borrowing on the budget in order to provide advanced technology development, such as CCS, requires a long process. Furthermore, the demand for CCS technologies in ASEAN is still low, raising the risk of investment.

The competitiveness of alternative low-emission technologies refer to how well CCS can compete with other technologies that also aim to reduce emissions, considering factors such as cost and regional availability [28]. This competitiveness determines whether CCS will be chosen over other options, particularly in areas where other low-emission solutions are limited or not feasible such as industry, hydrogen production, power generation, and carbon-based fuel production. Southeast Asia faces significant challenges in the competitiveness of low-emission technologies due to the low availability of low-emissions electricity and hydrogen, as well as the fact that CCS cost projections for the coming decades are unlikely to be competitive, especially given the expected decline in renewable energy and storage costs [118].

Three-quarters of newly planned CCS projects in the region use gas processing which mainly serves to separate the excess "reservoir-associated CO_2" from the valuable components of the gas. Gas processing is not meant to reduce emissions from all emissions, including the upstream and downstream emission industries. However, it aims rather to somewhat minimise production-related emissions (emissions owned by the industry) from gas with excessive CO_2 content [118].

Therefore, in the context of a certain rising concern about the importance of CCS technologies, the host countries need to understand the implications of the various CCS investment drivers, such as the internal carbon pricing (ICP) policies of investing companies for the potential of CCS projects. Through the ICP, companies voluntarily embed a "shadow: carbon price into their business decisions, which should have already moved the investors' baseline scenario. There is still a crucial need to find a fair division of CCS cost allocations between the host government and the investor.

Table 6.2 Summary of the current challenges related to the economic viability of CCS deployment in ASEAN

Country	Economic Viability Challenges
Brunei Darussalam	1. **Levelling the playing field with unabated facility:** Economic dependence on oil and gas may create a conflict in establishing aggressive carbon pricing strategies. 2. **High up-front investment:** Private sector credit remains low due to the low economic diversification. For this reason, there are concerns that implementing carbon pricing would create a fiscal burden.
Cambodia	**High up-front investment:** Insufficient financial support
Indonesia	1. **Levelling the playing field with unabated facility:** A low carbon tax rate is considered less attractive to investors. Fossil subsidies are obstacles to increasing domestic demand for green energy.

Country	Economic Viability Challenges
	2. **High up-front investment:** There is no Financial Services Authority (OJK) capacity to ensure quality, reliability and integrity of carbon credits.
Lao PDR	**Levelling the playing field with unabated facility:** The scope of carbon credit remains limited because of the non-existence of regulations for carbon pricing and credits
Malaysia	**1. Levelling the playing field with unabated facility:** Facilities without CCS technologies may face higher operational costs compared to those with carbon capture, creating competitiveness issues that hinder CCS adoption. **2. High up-front investment:** High costs of CCS technologies significantly hinder adoption, especially for financially constrained companies. **3. Competitiveness with alternative low-emission technologies:** Malaysia's development of CCS technologies relies on international cooperation and support, requiring alignment of domestic policies with international regulations like the London Protocol and the EU CCS Directive.
Myanmar	**High up-front investment:** The economy shrank during the COVID-19 pandemic and the period immediately following the military coup. Economic activity has remained weak and constrained.
Philippines	**1. High up-front investment:** The Philippines Energy Plan 2020-2040 allocates USD 170 million for exploration, development and production from 2023 to 2040, including CCS technologies for coal. However, this investment is insufficient for effective CCS development, with no details on external funding. **2. Competitiveness with alternative low-emission technologies:** • Carbon capture readiness is only 22 from in a 100 index • It does not have a deep pool of pilot and operational-project proof points across sectors and countries to demonstrate technological readiness
Singapore	**1. High up-front investment:** Lack of regulations for public-private partnership (PPP) to fund hydrogen development. **2. Competitiveness with alternative low-emission technologies:** • High-cost risk of hydrogen development • High-cost of CCS technologies
Thailand	**1. High up-front investment** • Thailand Bank funding requires green companies with over three years of operation, limiting MSME participation without government help. • Green bond issuance is new, with Thai businesses issuing bonds worth over $1 billion. • The country is developing national financial incentives and seeking international funding and support. **2. Competitiveness with alternative low-emission technologies:** Lack of knowledge and capacity

Country	Economic Viability Challenges
Viet Nam	1. **Levelling the playing field with unabated facility:** the strategy for optimising carbon pricing for CCS development remains unclear as the carbon credit (2025) and carbon market (2028) are yet to start. 2. **High up-front investment:** Low awareness and capacity of the MSME, making the priority of green investment and green business low; Credit worthiness of EVN (the main role player of SOE controlling electricity and power supply in the country) financial performance and credit structures remain vulnerable. 3. **Competitiveness with alternative low-emission technologies:** No collaboration for CCS tech to increase competitiveness.

Source: *Authors' compilation based on* [28].

Among the AMS, only Indonesia and Singapore have set carbon tax rates. Though it has been delayed until 2025, Indonesia's carbon tax of USD 2.11/tCO_2eq is perceived as being insufficiently high enough to encourage industries to switch to green business. According to the International Monetary Fund (IMF), the rate is one of the lowest globally, and it would be hard to persuade industries to switch their energy use to lower-emission technologies [119]. The tax rate is far lower than the carbon tax rate suggested by the World Bank and IMF, which is between USD 30 and USD 100 per ton of CO_2eq for developing countries. Although there are no plans to increase it, this tax marks a significant first step, as few developing countries have implemented such a measure.

Indonesia's decision to impose a very low carbon tax rate is primarily driven by the need to balance economic and environmental goals. The country has set ambitious targets to reduce its GHG emissions, but it also faces significant economic challenges, especially following the COVID-19 pandemic. Given the country's economic conditions, the low carbon tax rate of IDR 30 per kilogram of CO_2 equivalent (CO_2eq) or USD 2 per ton of CO_2eq is seen as a more manageable and feasible step towards reducing emissions [120]. This approach is also influenced by the fact that Indonesia's carbon tax is part of a broader tax reform package aimed at increasing the country's tax revenue and improving its tax-to-GDP ratio. The low tax rate is expected to be more palatable to businesses and industries, which would otherwise face significant costs from a higher tax rate. Additionally, the low carbon tax rate is seen to encourage industrial innovation and the shift to low-emission technologies, while also providing a relatively low burden on businesses and households.

Next is Singapore which raised the carbon tax to SGD 25/tCO_2eq in 2024. From 2019 to 2023 it was SGD 5/tCO_2eq. This was seen as a transition period to give the industry time to adjust to it. The tax will increase to SGD 45/tCO_2eq in 2026 and 2027, with a view to reaching SGD 50-80/tCO_2eq by 2030. However, from a business perspective, the carbon tax rate is considered unattractive. In addition to the carbon tax, the Singaporean Government has introduced various incentives and funding schemes to support businesses in their transition to a green economy.

Several initiatives in Singapore provide funding to support energy efficiency and green projects. The Economic Development Board (EDB) administers the Resource Efficiency Grant for Energy, which supports manufacturing companies by funding up to 50% of qualifying costs for energy-efficient technologies [41]. Similarly, the National Environment Agency's (NEA) Energy Efficiency Fund offers up to 70% funding for companies to adopt energy-efficient technologies and decarbonise early. The Green Buildings Innovation Cluster Demonstrations Scheme (GBIC-Demo) supports building owners and developers in showcasing innovative energy-efficient technologies [121].

6.2 Long lead times

The second parameter of the key challenges for CCS deployment in ASEAN is related to the **long lead times** required for CCS projects. It refers to the significant time it takes to complete the various stages of a CCS project, from conception to commissioning. **Firstly, project structure and timelines** refer to the detailed phases involved in developing a project, which include feasibility studies, FEED studies, project development, design, permitting and financing. **The second challenge relates to the duration of past CCS projects:** typically, around six years. The challenges appear in terms of how long the application for CO_2 capture takes, the fate of the CO_2 (dedicated storage or utilisation) and infrastructure requirements. However, some projects have taken significantly longer; for example, for the Quest project in Canada, it took almost four years just to complete the subsurface modelling. **Third, perspectives for future lead times** imply the need to accelerate project timelines to meet the ambitious goals of the Net Zero by 2050 Scenario.

Achieving shorter lead times will require continuous innovation, improved project management and more efficient resource allocation. However, significant challenges such as securing financing and managing project complexity must be addressed. First-of-a-kind projects often encounter high uncertainty in cost estimates, which can result in delays and budget overruns, further complicating efforts to reduce lead times. Several AMS have announced their interest in using CCS technologies. However, according to IEA CCUS data projects, most of the developments will start in 2025 and be operated efficiently in 2030 [15]. Therefore, further analysis of CCS project readiness in ASEAN needs to be prioritised.

Table 6.3 Summary of current challenges in long lead times of CCS deployment in ASEAN

Country	Long lead Times Challenges
Indonesia	**CCS project structure and timelines:** Structural integrity issues of the proposed injection well; Questionable geologic suitability for CO_2 storage; Broader technical expertise needed causing additional individual consultants to be engaged to support these activities. **Duration of past projects:** According to ISO 27914 and ISO/FDIS 27916, injection well design and construction must ensure long-term CO_2 containment and safety.

Country	Long lead Times Challenges
	However, these standards alone are insufficient to evaluate well integrity, as they lack specific criteria, measurement duration, and parameter ranges based on industry best practices.
Malaysia	**CCS project structure and timelines:** Final investment: 2022 > January 2023: Baker Hughes secured the contract for supplying carbon dioxide compression equipment from MMHE> 2025 start construction> 2026-2028 expected operation
Thailand	**CCS project structure and timelines:** Thailand has not yet achieved the implementation or partially implemented the CCS roadmap. - **Regulations** 2011-2015 (partially complete): Identification of the governmental agency that can be responsible for CCS development; definition of principles for Thailand CCS regulations within international context. 2015-2020: Establishment of Thailand CCS regulations. - **Incentives** 2011-2015 (minimal completion): CCS projects in Thailand qualified for CDM; seek international funding opportunities; conclusion on potential national incentives reached. 2015-2020: Develop potential national financial incentives. - **Stakeholder Engagement** 2011-2015 (minimal completion): Ensuring public concerns are answered; engage key stakeholders in CCS development. 2015-2020: public understanding of the key role of CCS in climate change. 2020-2030: stakeholder acceptance of CCS.

Source: *Author's compilation based on* [28].

6.3 Project complexity

The third parameter, **"Project Complexity",** refers to the intricacies and challenges involved in managing and coordinating the various stages and components of a CCS project. This complexity can arise from several factors: **project risks**; **cross-chain coordination**; **access to CO_2 management infrastructure**; **multimodal and cross-border carbon management infrastructure**.

The **project risks** in CCS deployment encompass several categories. Technical risks involve potential failures at any stage of the CCS value chain. Cross-chain risks arise when the failure or unavailability of one part of the chain affects other actors within the system. Legal and regulatory risks stem from uncertainties in legal standing, particularly concerning leaks and environmental impacts. Health and safety risks pertain to potential hazards associated with CCS operations. Social acceptance risks relate to public perception and potential opposition to CCS deployment. Finally, market and financial risks involve fluctuations in carbon prices, energy prices and other market factors that can significantly impact the economic viability of CCS projects. These diverse risk categories contribute to the overall complexity of CCS projects and must be carefully managed for successful implementation.

Project risk is divided into five categories: legal risk, health risk, technical risk, market and financial risk, and social acceptability. We found that legal risks occur in most of the AMS. Regionally, the legal risks stem from a lack of comprehensive CCS regulations. While Indonesia has the most mature CCS regulation, other countries such as Thailand, Viet Nam, the Philippines and Malaysia have shown interest in CCS. However, the regulations still need to include major implementation support for CCS. Additionally, most of the AMS have not signed the London Protocol which would create a transportation risk for carbon trading with other countries and hinder the CCS hub goals.

Cross-chain coordination involves ensuring effective collaboration between various parts of the CCS value chain to facilitate project success. This includes matching emission sources to sinks, where CO_2 emitters must have access to the necessary CO_2 transport and storage infrastructure to plan their projects effectively. Additionally, tracking capture and storage developments is vital; developers of CO_2 management services need to secure demand through offtake agreements with CO_2 emitters to justify investing in costly CO_2 infrastructure. This coordination is essential for the seamless integration and functioning of the entire CCS network.

Currently, ASEAN does not yet have regional **cross-chain coordination.** Regional cross-chain infrastructure still languishes in the joint study and research stage, such as the Asia CCS Network [11]. ASEAN countries are still new to CCS implementation. The most mature country with regard to advanced regulatory frameworks and policies is Indonesia, while the rest of the countries still focus on exploring, developing and observing the implementation of CCS. Indonesia and Singapore are currently making progress in collaborating on the establishment of carbon cross-border provisions.

Access to **CO_2 management infrastructure** for CCS refers to the availability and operational status of the necessary facilities and systems required for transporting and storing CO_2. This infrastructure is critical for the successful deployment of CCS projects, as it ensures that captured CO_2 can be efficiently transported from emission sources to storage sites. The region faces a lack of international regulations, which presents a barrier for transport and storage infrastructure to accommodate trans-border carbon activities.

ASEAN faces three main challenges in **CO_2 management infrastructure**: 1) The lack of international regulations presents a barrier for transport and storage infrastructure, 2) Concern about selecting more secure sites with more robust MRV corroboration as Southeast Asia is located in the ring of fire, and 3) The greater quantity of energy used in transporting carbon by ship for the liquefaction and fuel use [11], [40].

Indonesia, Singapore, Thailand and Viet Nam face specific challenges. Indonesia struggles with incorporating regional considerations into CCS decision-making, as control remains with the central government, hindering alignment with local needs and potentially causing issues with social acceptance among local communities. Singapore faces high capture costs as most of the carbon dioxide emissions are dilute. In Thailand, most industrial activity and emissions are concentrated around Bangkok, suggesting the potential for a CCS capture cluster, though this issue has not been extensively studied. Lastly, Viet Nam faces two main challenges: limited assessment of storage capacity and the need to develop diverse CCS schemes beyond EOR production.

Another concern arises from the need to select safer and more robust sites in accordance with stringent MRV. Large parts of Southeast Asia are within the "Ring of Fire", extending around much of the rim of the Pacific Ocean and known for frequent earthquakes and volcano eruptions [11]. This does not preclude the possibility of geological storage in the region, but it underscores the importance of rigorous site selection. Additionally, continuous measurement, monitoring and verification during and after operations will be crucial to ensure the long-term liability of the development of CCS projects.

Related to a **multimodal transport** system for cross-border CCS, the AMS encounter some barriers related to regulation, including non-compliance with the London Protocol that prohibits the export of CO_2 for geological sequestration. Even though the protocol was amended in 2009 to facilitate transboundary CO_2 transport, it is yet to enter into force because it has not met the minimum required number of state ratifications [122]. The need to establish regional regulations for transport and storage remains a crucial issue. The AMS are connected mainly by maritime routes, which are more complicated. This raises another concern: the marine transport regulations for carbon trading, particularly concerning leakage, should be clarified. The existing regulations, such as the London Protocol, present complex territorial and transboundary regulatory challenges in the Asia-Pacific region.

Furthermore, the stringent environmental, social, and governance (ESG) screening criteria used by financial institutions make it challenging for private investors to obtain the necessary bank loans for large-scale CCS projects. This financial obstacle could be alleviated if national governments recognised CCS as a low-carbon energy solution, thereby easing the restrictions [123]. There is an urgent need to clarify the issues, scope and applicability of existing international laws, particularly the London Protocol.

As the region has the potential for large CCS hubs, ASEAN may need complex **multimodal and cross-border CO_2 management**, including of transport systems. Such complex, potentially cross-border infrastructure can present several challenges. Two main problems related to this in ASEAN are unavailability of pipelines due to geological conditions and an insufficient international framework that regulates CO_2 transboundary activity. First, some regions lack pipelines due to earthquake-related issues, terrain and soil quality [122].

Geographical challenges play a significant role in ASEAN. Unlike European countries, which are connected by land, the AMS are primarily linked by maritime routes, making the logistics more complex. Additionally, cross-border collaboration in ASEAN is not as developed as in Europe. Europe benefits from more extensive schemes and regulations, providing a stronger foundation for cooperation with multinational companies. Second, the regulatory barriers arise due to the fact that the region is not party to the London Protocol. Shipping CO_2 also offers greater flexibility and contingency in the CCS value chain, particularly where there are numerous storage facilities able to accept shipped CO_2 [124]. However, shipping CO_2 by ship requires extra assessment of the environmental impacts on the marine environment.

Certain high-emission applications—such as power plants, oil and gas, and chemical production plants—are ideal candidates for a CCS hub because their characteristics make them more appropriate for integration into an industrial cluster. As cement production plants and BECCS facilities typically operate on a smaller scale and are more widely distributed, they are not as emissions intensive as other industries. In Southeast Asia, around 45% of the emissions from power plants and 20% from the cement, steel, iron and chemical sectors could be linked up within industrial clusters, but only a few storage hubs are currently planned, in Indonesia and Viet Nam [11]. This represents a challenge to CO_2 **management infrastructure** as it differs among the AMS.

Table 6.4 Summary of project complexity of CCS deployment in ASEAN

Country	Project Complexity Challenges
Brunei Darussalam	**Project Risk** - **Safety and environment risk**: low adaptive capacity due to the lack of adequate disaster preparedness, vulnerabilities in the agricultural sector, and low scores on governance and business environment. - **Social Acceptability**: most MSMEs are still in an early stage of development. This challenges the government to create a more engaging stakeholder programme to help MSMEs develop comprehensive policies and assistance in encouraging businesses to undergo green transitions.
Cambodia	**Project Risk** - **Legal risk:** The lack of clear government investment policies, incentives and mechanisms is hindering private sector investment and participation. - **Cross chain risk:** Long transport distances result in more emissions; secure storage of captured carbon requires extensive isolated land area.
Indonesia	**Project Risk** - **Health risk:** Need to mitigate the risk in the context of commingled carbon, ensuring quality specifications, and addressing leakage risk. - **Technical Risk:** Unclear storage resource assessment to ensure safe and secure storage. - **Legal Risk:** The MEMR Regulation No, 2/2023 lacks long-term liability post-site closure. PR 14/2024 does not explicitly mention compliance with the London Protocol or consider any international implications. - **Social Acceptability:** Low awareness of the Society for CCS technologies and its impacts.

Country	Project Complexity Challenges
	Cross Chain Coordination: Limitations related to corrosion simulation in the MRV system for the project. **Access to CO_2 management infrastructure: sectoral and regional considerations:** Lack of regional regulations. **Multimodal and cross border CO_2 management infrastructure:** Lack of regulatory frameworks for non-upstream oil and gas activities to participate in CO_2 transport storage activities; Permitting regulations require the Contractor to be an Indonesian incorporated company or a foreign company that creates a permanent establishment in Indonesia.
Lao PDR	**Project Risk** - **Technical Risk:** public and private sectors face a shortage of skilled personnel in this area and often depend on international experts for preparing documents required for entering the carbon credit market. - **Legal Risk:** difficulties in enforcing the law due to poverty issues in designated forest areas. This requires strengthening forest protection law enforcement. Revenue from the sale of carbon credits and funds from development partners will be used for this purpose. The regulatory framework for CCS in Laos is still insufficient. The country needs to establish a comprehensive legal and regulatory framework that supports the development of CCS projects. - **Social Acceptability Risk:** CCS projects often face public resistance due to concerns about the environmental and health impacts of CO_2 storage. Laos will need to engage in effective public outreach and education to build trust and acceptance of CCS projects.
Malaysia	**Project Risk** - **Legal Risk:** No specific regulations for CCS. Malaysia has yet to develop a policy and regulatory framework on CCS on a national scale. - **Social Acceptability:** Public awareness and education about the benefits and applications of CCS technologies are crucial for its widespread adoption and acceptance. **Cross-Chain Coordination:** Lack of dedicated CUS management agency; only small PETRONAS Carbon Management Division. **Multimodal and cross border CO_2 management infrastructure:** Malaysia has conducted scoping studies that have explored the legal and regulatory aspects of implementing CCS and has identified insufficiencies in its existing system.
Myanmar	**Multimodal and cross border CO_2 management infrastructure:** Myanmar has yet to establish policies and regulations specifically for CCS. However, Myanmar has shown interest in this area.
Philippines	**Project Risk:** - **Legal Risk:** No specific CCS regulations established. - **Social Acceptability:** Public awareness of CCS is relatively low. - **Technical Risk:** No pilot project has been made. - **Environment Risk:** Only 4 power plants, with only 20 years of remaining life in which to employ CCS capture. Given the immaturity of technology and the government's lack of readiness, significant progress in CCS is unlikely. **Access to CO_2 management infrastructure: sectoral and regional considerations:** The potential for early large-scale CCS projects outside Manila may be limited due to a lack of concentrated emission sources.
Singapore	**Project Risk** - **Cross-Chain Risks:** Singapore lacks suitable domestic geological storage sites for CCS and will have to partner with other countries for cross-border CCS. This however

Country	Project Complexity Challenges
	imposes significant cross-chain risks for Singapore emitters – though this can be mitigated should there be G2G agreements for cross-border CCS. - **Market Financial Risk:** Carbon capture costs are relatively high in Singapore due to the dilute CO_2 streams and partly due to the need for retrofitting existing plants. **Multimodal and cross border CO_2 management infrastructure** - Implementing carbon capture may require significant redesigning of existing plants, particularly in industries like refineries where the infrastructure layout may pose challenges for retrofitting. - Processes with high output pressure of flue gas and high concentrations of CO_2 generally have lower capture costs. However, in Singapore, sources with such characteristics represent only a small amount of the total CO_2 emissions.
Thailand	**Project Risks** - **Legal Risk:** existing regulatory frameworks can support pilot projects but would require modifications to support full-scale or commercial investments. - **Financial and Market Risk:** new investments are needed to promote renewable energy along with hydrogen production, storage, and transportation infrastructure. - **Technical Risk:** The technologies in energy intensive industries like cement, iron and steel are long lived assets with a minimum lifespan of 20 years. These infrastructures, once built, are hard **to replace without policy interventions and incentives**. **Multimodal and cross border CO_2 management infrastructure:** Most Thai gas fields are still under primary depletion and therefore not ready for CO_2 storage**.**
Viet Nam	**Access to CO_2 management infrastructure:** Limited assessment of storage capacity considering that many industrial emitters – including cement and steel manufacturing – are concentrated in the north.

Source: *Authors*

From the questionnaires and FGD, it was found are that the legal and regulatory risks ranked first, i.e. the most crucial to be tackled. The legal and regulatory risks were also found to affect or be related to all three key common challenges (**Table 6.5**). In the case of Thailand, private companies are seeking clarity on the regulations related to CCS projects before moving forward with any business decision.

This is also in line with the key point highlighted by the AMS representatives during the FGD: absence of a regulatory framework or policies concerning CCS is a key challenge in ASEAN. Establishing robust policies and regulations on CCS would facilitate the efforts in tackling economic, technological and project challenges in ASEAN. Technology risks and resource risks are on the second and third ranks of project risk that the AMS representatives consider need to be tackled. Other risks are more related to both technology readiness and project viability of CCS projects in ASEAN (**Table 6.5**).

Table 6.5 Project risks' ranking based on the impact of project implementation

Rank	Risk	Related common challenge			
		Fin*	Econ*	IG*	Pro*
1st	Legal and regulatory risk	X	X	X	X
2nd	Technology risk			X	X
3rd	Resource risk	X	X		
4th	Market risk	X	X		
5th	Performance risk			X	X
6th	Natural hazard risk				X
7th	Social and political risk			X	X
8th	Scope and environment risk			X	X

Note: ** Fin is financial availability; Econ is economic viability; IG is Innovation Gaps; and Pro is project design*

Source: *Authors.*

6.4 Innovation Gaps

The fourth parameter involves closing **innovation gaps**. As related to the level of the CCS system's CO_2 removal ability, there are significant differences between the current state of technology and the requirements needed to achieve net zero emissions by 2050. These gaps are particularly pronounced in CCS technologies that are still at the demonstration or prototype stage, which are critical to meeting the ambitious goals of the Net Zero by 2050 Scenario. This indicator gauges **the level of technological maturity** to efficiently capture carbon with cost-friendly budget.

The CO_2 removal technologies, particularly Direct Air Capture (DAC), become essential, and progress has recently been demonstrated [28]. However, DAC has its disadvantages since the technology targets the extremely low CO_2 concentration in air, which makes the process costly and energy intensive [125]. A study suggests that to overcome the barriers with current CCS technologies a commercially viable hybrid system comprising more than one technology–CO_2 capture, separation, transport, utilisation and /or storage–needs to be developed [125].

While numerous technologies hold promise for reducing CO_2 emissions, the global rollout of CCS projects remains insufficiently rapid to achieve the net zero CO_2 emissions goal by 2050 [125]. The readiness of the AMS in terms of CCS technologies, as indicated by the Global CCS Institute, is generally low. At the regional level, ASEAN faces challenges due to limited experience and preparedness with these technologies. The region lacks a substantial number of pilot projects and operational examples across various sectors and countries to validate technological readiness, such as CO_2 separation capture, and crucial technical de-risking, like the capability to safely reuse existing wells [14]. This can result in a slower adoption rate and higher costs associated with learning from others.

Additionally, the region has minimal technical expertise in managing reservoirs even for CO_2-EOR, which is among the most mature technologies in CCS, or any other form of subsurface CO_2 storage [13]. According to the Global CCS Institute, the Carbon Capture Readiness Index, which includes the indicator of technical ability to store CO_2, is below 50 out of 100 in some AMS. The readiness index levels are as follows: Malaysia (31), Indonesia (30), Viet Nam (29), and both the Philippines and Thailand (22), while the average index in Asia is 35 [126].

6.5 Key highlighted challenges

The AMS, particularly Indonesia, Malaysia, Thailand and Viet Nam, showcase significant potential for CCS projects. With vast oil and gas fields offering substantial CO_2 storage capacity, these nations are well-positioned to play a pivotal role in the global efforts to mitigate climate change through carbon sequestration. Indonesia emerges as the leader in the region with the most active planned and launched CCS projects. Malaysia is second in terms of readiness to deploy CCS. It is solidifying its position in advancing carbon capture technologies in partnership with global stakeholders. Other countries such as Thailand, Viet Nam, and Singapore are still in the early stages of deploying CCS.

While the AMS exhibit substantial potential and commitment to CCS initiatives, the region faces specific challenges involving **the economic viability, long lead times, project complexity and innovation gaps.** Our study shows that the challenges in ASEAN are related to the financial regulatory framework, immature pilot projects and technological provision. Among them, the current cost of CCS technologies is the most important challenge hindering the deployment of CCS project in the region. The IEA 2020 report implies that the projected reduction in the cost of CO_2 capture for coal power is from around USD 65/tCO_2 in 2020 to USD 40/tCO_2 in 2070, a value which is certainly still far from being achieved by the majority of the AMS [12]. **Table 6.6** summarises the key challenges faced by ASEAN related to CCS deployment in the region.

Table 6.6 Summary of key challenges of CCS deployment in ASEAN

Category	Regional Challenges	Country
	Economic Viability	
Levelling the playing field with unabated facility	• Carbon price estimation: chance unlikely to reach more than USD50/tCO_2 given the non-existent CCS business model • Economic efficiency and business risks bar the path to commercialisation, particularly unreadiness for carbon pricing	All AMS

Category	Regional Challenges	Country
High up-front investment	• High capital costs, but low government support as national budget is already constrained after pandemic • Regional governments are hesitant to take on more debt, especially after large loans during the pandemic • Large-scale investment in renewables remains too costly for the private sector alone to fill the gaps	All AMS except SG
Competitiveness with alternative low-emission technologies	• Low availability of low-emissions electricity and hydrogen • Several CCS cost projections in the next decades show that it is unlikely to be competitive, particularly given the slight decline of renewable energy and storage costs	BN, MY, PH, SG, TH, VN
	Long Lead Times	
CCS project structure and timelines	• Several countries have made announcements to deploy the projects, but detailed timelines for studies, design, development and construction have not been publicly disclosed	ID, MY, TH, VN
Duration of past projects	• Most of the projects in Southeast Asia are still in the planning stage, with the majority projected to start in 2025	ID
Perspectives for future lead times	• There are factors that cause further delays due to the present risks of facing more social opposition, including environmental impacts	Not yet established in any AMS
	Project Complexity	
Project risks	• Potential risks for the current policies in terms of addressing technical, cross-chain, market and financial, legal and regulatory, climate, health, safety and environment issues, as well as social acceptability • Lack of investment, including public-private partnership	All AMS
Cross-chain coordination	• Singapore and Indonesia still in talks to coordinate carbon cross-border transport • Regional cross-chain coordination does not yet exist	ID, MY, MM
Access to CO_2 management infrastructure: sectoral and regional considerations	• Lack of international regulations is a barrier for transport and storage infrastructure • Concern about the capability of MRV	ID, MM, PH, VN
Multimodal transport system for cross-border CCS	• AMS are not parties to the London Protocol	ID, LA, MM, SG, TH
	Innovation Gaps	
Lack of correspondence between the levels of innovation and the technologies and CO_2 removal ability of the CCS system	• Limited experience and preparedness • Low capacity of CCS technical knowledge • CO_2 removal considered new	All AMS

Note: BN: Brunei Darussalam; KH: Cambodia; ID: Indonesia; LA: Lao PDR; MY: Malaysia; MM: Myanmar; PH: Philippines; SG: Singapore; TH: Thailand; VN: Viet Nam

***Source:** Authors' compilation based on* [11] [17] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38].

When considering CCS technologies, the **high up-front cost** is the key challenge affecting **the economic viability** and hindering the deployment of the CCS technologies in ASEAN. Thus, it is necessary to seize **innovative financing models** and **continued international collaboration** to overcome these challenges effectively.

Studies of Indonesia, the country with the most detailed coverage, shows that financial framework obstacles are caused mainly by the difficulties in attracting high-upfront investment and levelling carbon pricing to enable unabated facilities. CCS technologies are highly costly to develop, thus making it crucial to attract funding. The main problem is that for emerging economies like Indonesia, depending solely on government funds to expand CCS is impossible. The government budget has been burdened by the pandemic, making it too costly to develop CCS without private support. Attracting high upfront investment means that the Government should ensure that the flow of the carbon market, including the regulations and commercialisation path, is open and robust.

The deployment progress is further hampered by **the long lead times** associated with planning and executing projects, particularly those pertaining to infrastructure for CO_2 storage. This parameter refers to the significant time it takes to complete the various stages of a CCS project from conception to commissioning. **Achieving shorter lead times will require continuous innovation, improved project management, and more efficient resource allocation.** To do so**, securing financing and managing project complexity** must be addressed. **Project complexities** evolve alongside the emergence of new business models calling for improved coordination throughout the value chain and management of shared cross-border CO_2 transport and storage.

The AMS also face a significant challenge in the **innovation gaps** between the currently used technologies and the requirements for achieving net zero emissions by 2050. All of them are still in the early stages of relevant technology development and lack the necessary pilot projects and technical expertise to advance CCS capabilities. The paucity of such projects is due to several critical factors. First, since most AMS exhibit limited experience and preparedness for CCS technologies, the development and implementation of such projects are impeded [11]. The absence of operational commercial or demonstration projects exacerbates this issue, as there is no existing infrastructure or operational expertise available for reference. Additionally, the region has not fully investigated potential CO_2 storage resources, a critical component of CCS [118]. This lack of comprehensive understanding and availability of suitable storage sites further hinders the development of pilot projects in ASEAN. This **underscores the need for increased R&D investment, capacity building, and knowledge sharing to accelerate technology readiness and deployment.**

Chapter 7

CCS Deployment Roadmap

7.1 Stakeholder Mappings of the CCS Value Chain

Before presenting the roadmap, it is important to give a preliminary mapping of the stakeholders involved. As CCS deployment in ASEAN is still in the early stages (market creation), increasing communication and collaboration among CCS stakeholders is crucial to fostering, understanding and gaining support for upcoming initiatives. [11] To support the establishment of this coordination, the identification and mapping of the stakeholders involved in the CCS full chain system in ASEAN, on the basis of Indonesia's experience, is presented in **Figure 7.1** The identified stakeholders are then mapped into each stage of the CCS full chain and are also further categorised based on the degree of interest and influence. High interest indicates the current priority stage of CCS projects in Indonesia. High influence also indicates the strong impacts of the stakeholders involved in supporting the early stages of CCS deployment in Indonesia.

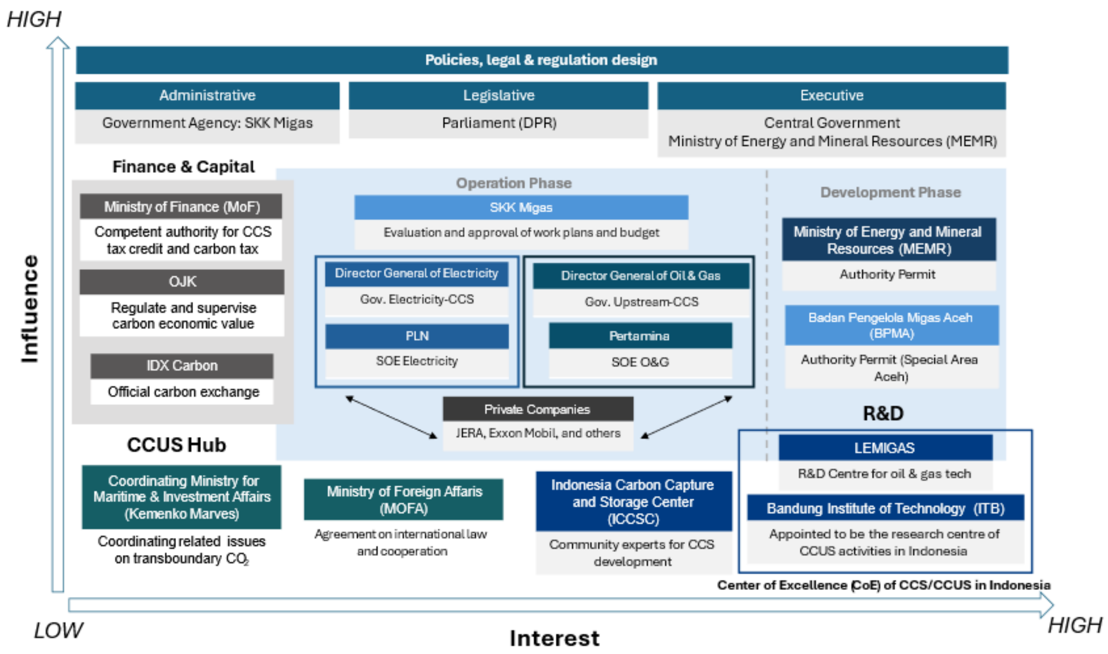


Figure 7.1 Stakeholder map of CCS full chain (Indonesia case)
Source: *Authors'compilation based on [50], [53], [61-66], [75], [79], [128-130], [132].*

In the case of Indonesia, MEMR Regulation 2/2023 and PR 14/2024 constitute the legal umbrella for the CCS and CCUS projects. Various stakeholders are involved in the formulation of these legal products, such as the MEMR and other central government institutions as the executive power. The MEMR has the most influence on and interest in

CCS deployment due to its responsibility to build and design the required legal framework. In this early deployment stage of CCS and CCUS, the MEMR has a high degree of interest and influence.

Key elements needed to establish the CCS legal system include the formulation of administrative law and guidance for the activity implementation by the administrative agencies. In this case, the SKK Migas has the power to design the technical regulation of CCS in oil and gas work areas and to influence the implementation of the administrative law. Meanwhile, the parliament has the authority to affect the project, but may not be directly interested in this as it has competing priorities and agendas. The parliament is currently not involved in the CCS policy design, but it has the duty to monitor the quality of the executive government' works. The involvement of the Indonesian House of Representatives (DPR) might be required to ratify the international legal framework of transboundary CO_2 activities.

The deployment of a **CCS full chain system** requires effective governance among stakeholders involved along the system. The CCS full chain system includes two key phases (*development and operation phases*). In the *development phase* of the CCS project, the MEMR carries out the first field development plan which can approve or reject proposals from the contractors based on considerations from the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas) and the Aceh Oil and Gas Management Agency (BPMA) [49].

Within the operation phase, SKK Migas is the main actor in Indonesia. SKK Migas is the government body implementing the management of upstream business activities in the oil and gas sector under the MEMR which evaluates and approves the workplans and budget for CCS activities [75]. Meanwhile, BPMA, jointly managed by the Indonesian and Acehnese governments, is constrained within the Aceh jurisdiction which has the role to administer oil and gas activities in its territories [126]. Therefore, though SKK Migas has more influence, BPMA has a high level of interest to defend Acehnese citizens' interests in CCS activities in oil and gas work areas. Other actors in the operation phase include:

- Director General of Oil & Gas, MEMR
- Director General of Electricity, MEMR
- The State-owned Enterprise (SOE) Oil & Gas: Pertamina
- The State Electricity Company: PLN
- The private sectors that have established projects based on the Memorandum of Understanding with SOE. Currently, in the oil and gas sectors, KNOC and Exxon Mobil agreed to cooperate on a CCS study with Pertamina [128]. while JERA and Medco established collaboration with PLN for CCS activity in the electricity sector [129], [130]

Under the enabling stakeholders (finance and capital), we identified the Ministry of Finance as the key authority above the Financial Services Authority (OJK) and the official carbon exchange in Indonesia, IDX Carbon. These are stakeholders who have a high impact over the feasibility of the CCS technologies' finances, though they may not engage deeply. It is expected that the costs of CCS technologies will fall in the coming years, they are still considered high. Improving the economic viability of CCS projects is crucial, but this will only occur if strong regulatory frameworks are in place. At present, the tax incentives offered to CCS contractors are considered pivotal. These falls under the ambit of the Ministry of Finance [53].

To promote the competitiveness of CCS, Indonesia has taken the approach of carbon pricing, such as monetisation of carbon credits in accordance with the regulations governing carbon economic value, namely, Presidential Regulation Number 98/2021 [50], [62]. The Minister of Environment and Forestry (MOEF) heads the general procedures for carbon pricing implementation [63], but the MEMR will guide the implementation of carbon pricing in the power plant sub-sector [64]. Moreover, carbon trading is carried out via carbon exchange, the IDX Carbon Indonesia through the approval of the Financial Services Authority (OJK) [66].

The development of CCS requires reliable and cost-effective technology. With rapid advances in carbon capture technologies, there needs to be an improvement in the determination of CCS costs as they are considered high relative to other alternative low-emission technologies. One of the main obstacles is the technological immaturity of CCS. There is currently little **R&D** devoted to CCS technologies in Indonesia, other than that carried out at the Center of Excellence (CoE) of CCS in Indonesia. The Directorate General of Oil and Gas appointed the Bandung Institute of Technology (ITB) with Lemigas to be the main research centre tasked with conducting the first pilot project on Gundih CCS [131]. Indonesia established the Indonesia Carbon Capture and Storage Center (ICCSC) in 2023 as the connection among CCS-related stakeholders to accelerate technology implementation through research, innovation and advocacy [132]. These stakeholders are deeply interested or at least enthusiastic about the project but wield minimal power or influence over its outcome. They may act as the government's advisors on CCS system.

Lastly, the **CCS hub** has a low degree of interest and influence as of now since the region is merely in the early stages of development. To date, Indonesia has signed a Letter of Intent (LOI) with Singapore on cross-border CO_2. It was signed by the Coordinating Ministry of Maritime Affairs and Investment (Kemenko Marves) of Indonesia and Singapore's Energy Market Authority (EMA)[79]. The transboundary sub-seabed CO_2 project will involve extensive cooperation agreements and international laws coordinated handled by the Ministry of Foreign Affairs (MOFA).

From the case of Indonesia, a general framework of stakeholders to be involved in CCS/CCUS can be identified (**Figure 7.2**) covering policy design, the development phase, finance and capital, R&D, and the CCS hub.

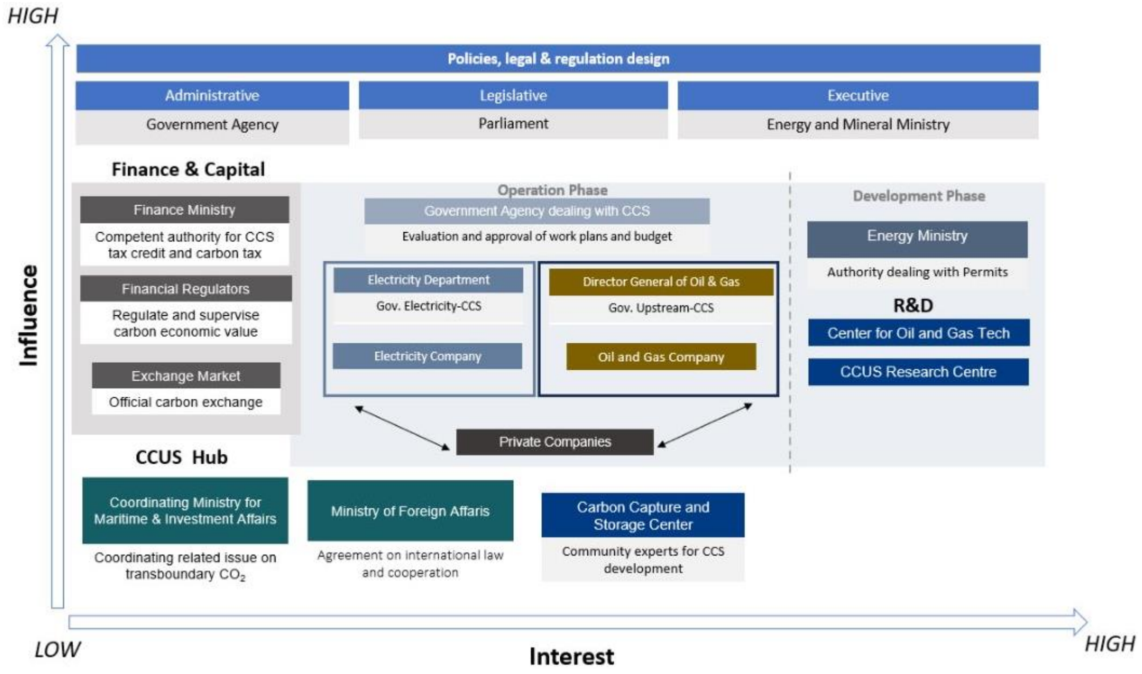


Figure 7.2 General framework of stakeholders to be involved in CCS/CCUS
***Source*:** Drawn by authors

7.2 CCS Deployment Roadmap

As the CCS development in ASEAN is still in the early stages (market creation stage), several strategies to mitigate the key challenges and to accelerate the readiness level of CCS technologies in ASEAN need to be developed. Five strategies and their corresponding action plans are proposed to be implemented during the short, medium and long-term periods (2025-2050) aligned with the ASEAN Carbon Neutrality Targets by 2050. These strategies and action plans refer to the key highlighted points of the previous chapters under the ASEAN contextual.

Strategy 1: Enhancing the economic viability of CCS development

Enhancing the financial and economic viabilities of CCS technologies is perceived as the first rank of key challenges that must be tackled in ASEAN. To enhance the economic viability of CCS technology development in the region, three action plans need to be urgently implemented during the short-term period (2025-2030) (**Table 7.1.**). The main objective of the plans is to reduce the cost of CCS projects, including the high capital cost and lower competitiveness of CCS compared with hard-to-abate industries. The first action is to develop or improve green financial instruments such as carbon pricing, with rates that are attractive enough to develop a local CCS ecosystem. Carbon pricing can provide significant cost reductions and enhance the competitiveness of CCS by requiring some high-emitting industries in ASEAN to pay a specific carbon price. The second action is to provide attractive grants, loans and tax credits for CCS infrastructure in ASEAN. These can be combined with any existing financial supports applied in some related industries such as on grid infrastructure. The third action is to provide revenue support through channels other than pricing (such as through contracts and the procurement process) to reduce the costs of CCS projects. These action plans are perceived as immediate urgent actions that must be implemented in the region. The last is the involvement of the state-owned utilities during the medium term (2031-2040). The implementation of the first strategy will involve mainly a collaboration between Ministry of Energy and Ministry of Finance.

Table 7.1 Action plans and timeline: Enhancing the economic viability of CCS development

Action Plans	Short term (2025-2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
Develop or improve green financial instruments, such as carbon pricing, with attractive rates to develop local CCS ecosystem				• Ministry of Energy • Ministry of Finance
Government provides attractive grants, loans, and tax credits for CCS infrastructure				
Revenue support, such as a regulated asset base model and particularly contracts for difference, to any operating CCS projects				
The involvement of state-owned utilities to CCS projects				

Legend:

Immediate Urgency | High Urgency

***Source*:** Authors

Strategy 2: Shorten long lead times and accelerate CCS domestic deployment

CCS projects that are currently operating have ranged from under 2 years to more than 10 years from announcement to commissioning. Therefore, shortening the extended lead times and speeding up the domestic deployment of CCS are crucial for ASEAN to align the global deployment pathway with the NZE. In line with the net zero target, strategy 2 will target reducing the current long lead times and enhancing mass deployments of CCS by 2050.

During Phase 1, in the **short-term (2025-2030)**, the focus will be on establishing a foundation for domestic CCS markets and initiating measures to expand the operational experience for CCS technologies or applications. The **immediate urgent initiatives** involve close coordination across stakeholders to plan the CCS projects for the **long-term**. However, due to the broad range and diversity of energy-related decision-making across sectors, the CCS governance and planning are extremely complicated and involve many different elements.

Additionally, in the **phase of market creation,** the initiative to accelerate the deployment project requires attention. With the goal of achieving the net zero target, it is necessary for governments to develop a deployment target for 2050 with divides goals into mid-term (2040) and long-term (2050). Although important, market creation does not require immediate implementation but is still necessary to be addressed in a timely manner to prevent any subsequent issues in planning mass deployment. Another action plan, typically handled after more pressing issues, is enabling first-mover CCS projects in the absence of a comprehensive CCS framework.

Following Phase I, **the mid-term (2031-2040)** explores domestic market growth. Implementing measures to reduce permitting and licensing lead times through clear regulations will be targeted at the end of the short-term and going into the mid-term. Moreover, high-level planning and indicative timelines of a CCS project, from the feasibility stage, project development stage, and procurement, construction, and commissioning also present the pathway to facilitate the mass deployment of CCS and reach mature status by 2050. However, these actions are not as immediate or critical as establishing greater coordination among the relevant stakeholders (such as the respective Ministry of Energy, Ministry of Environment, and R&D Centre) in ASEAN.

Table 7.2 Action plans and timeline: Reducing long lead times and accelerating CCS domestic deployment

Action Plans	Short term (2025- 2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
Facilitate first-mover CCS projects in parallel with the development of legal frameworks				• Ministry of Energy • Ministry of Environment • R&D Centre
Formulate and adopt legal frameworks to reduce permitting and licensing lead times				
Develop deployment target aligned with NZE pathways by mid-term (2030) and long-term (2050) as well as the storage site potential				
High-level planning and indicative timelines of a CCS project, from feasibility stage, project development stage, and procurement, construction, and commissioning				
Close coordination across stakeholders to plan the CCS projects				

Legend:

Immediate Urgency	High Urgency	Moderate Urgency	Low Urgency

***Source*:** Authors

Strategy 3: Manage project complexity and derisk CCS deployment

The shift towards the CCS hub model becomes increasingly complex, with implications for risk, timing, co-ordination and social acceptance, which need to be carefully managed. Therefore, CCS deployment in the region requires a top-down approach which includes the strengthening of legislation, public policies and regulation. A detailed study needs to be conducted for the proposed regulation that addresses project complexity and its risks. Moreover, strengthening the national CCS governance and institutions are also crucial to support the legal and regulatory frameworks.

During the **phase of market creation,** the development of CCS sites requires a robust legal framework. It is proposed to adopt regulations or use existing frameworks to define and classify CO_2, including its ownership across the CCS value chain. Moreover, regulation needs to consider the assessment of environmental review requirements, the use of permitting approaches, and risk management. The risk assessment involves ensuring safe and secure storage, such as storage resources, MRV plans and site closure procedures. These actions require swift attention from government.

Then during the end of the **short-term,** the government may consider regulating the long-term post-site closure and establishing the financial assurance to cover the long-term monitoring and management. The previous chapters encompass best practices from Indonesia and Malaysia in terms of legal frameworks on long-term storage liabilities. Moreover, in this period**,** attention will be directed to manage other emerging and strategic issues, such as regulating the overlapping surface and subsurface resource activities as well as transition from CO_2 EOR to dedicated storage operations.

As a continuation from Phase 1, **the mid-term** in this strategy will aim to ensure storage site safety for CCS market growth. Hence, it is proposed to conduct leakage risk assessment in transportation and storage processes as well as risk assessment on social, economic and environmental aspects to mitigate possible risks in the future. Moreover, to guarantee the safety of CCS for the **long-term**, ASEAN may need to adopt and harmonise the regional technical code, parameters and safety standards.

Finally, it is the intention that, ongoing monitoring and maintenance of CCS projects will be conducted to adhere to regulatory guidelines by the end of the **long-term** period. Hence, a centralised national committee or administrative agency needs to be dedicated to CCS development to monitor the ongoing projects and prevent such risks. The national agency will be advised by a regional advisory panel on the safety and security of ASEAN CCS projects for future global hubs. Moreover, governments are recommended to encourage early public engagement during project development by establishing mechanisms for public consultations for CCS developments.

Table 7.3 Action plans and timeline: Reducing project complexity and derisking CCS deployment

Action Plans	Short term (2025- 2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
Define and classify CO_2, including its ownership and title of CO_2 within the legal and regulatory framework				• Ministry of Energy • State-owned utilities • Private companies • Ministry of Foreign Affairs
Risk assessment, including legal, technical, market and financial, regulatory, health, safety, environment, social acceptability aspects				
Public engagement and consultation process				
Allocate liabilities across stakeholders and greater co-ordination				
Develop regulations on storage resource assessment, MRV plans, and site closure process				
Adopt and harmonise the ASEAN technical code and safety standard for CCS projects				
Integrate environmental impact assessment and permitting within the regulations				
Regulate the long-term post-site closure, including the				

Action Plans	Short term (2025- 2030)	Mid-term (2031-2040)	Long term (2041-2050)	Stakeholders
	Phase 1: Market Creation	Phase 2: Market Growth	Phase 3: Market Mature	
financial assurance of long-term site stewardship				
Regulate the overlapping surface and subsurface resource activities				
Formulate a regulation to transition from CO_2 EOR to dedicated storage operations				
Adhere to regulatory guidelinies and ongoing monitoring and maintenance				
Ensure long-term safe and secured storage				
Conduct a leakage risk evaluation to ensure safety and security in transportation and storage process				
Conduct social, economic and environmental assessments to mitigate possible risks in the future				

Legend:

Immediate Urgency	Moderate Urgency	Low Urgency

***Source*:** Authors

Strategy 4: Narrow the technology Innovation gaps

To narrow the technology innovation gaps, the immediate priority in the short term (market creation phase) is to **conduct comprehensive feasibility studies** on the technological readiness, socio-economic impacts and GHG emission implications. These studies should be led by R&D centres, which play a critical role in understanding the current landscape, identifying gaps and ensuring that the deployment of technologies is based on solid evidence tailored to regional needs. Simultaneously, it is crucial to **use existing technologies** to demonstrate, scale-up and deploy first. Utilizing available technologies while conducting feasibility studies allows for immediate action and real-world testing. Private companies, by driving innovation and investment, participating in feasibility studies, and providing complementary solutions, contribute to fostering competition and bringing diverse solutions to the table. This collaboration helps in scaling up successful technologies and identifying additional needs for **complementary technologies to be procured** afterward.

In the medium term (market growth phase) and long term (market mature phase), the region can then **establish standards and certifications for CO_2removal** (CDR) to ensure their reliability, effectiveness and safety. R&D centres, with their scientific and technical expertise, are crucial in developing these standards and certifications, ensuring that the technologies are ready for large-scale deployment. This also provides a regulatory framework that can foster innovation and investment in CDR technologies. Additionally, **integrating CDR technologies into the legal framework** is important to provide a structured approach to carbon management. SoEs, private companies and R&D centres can collaborate to ensure that these technologies are recognised and supported by law, facilitating their widespread adoption and contributing to long-term climate goals.

Table 7.4 Action plans and timeline: Narrowing the technology innovation gaps

Action Plans	Short term (2025- 2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
Utilise the available technologies to demonstrate, scale-up and deploy first				• State-owned utilities • Private companies • R&D Centre
Feasibility studies on technology, society, economy and GHG emissions in preparation for application				

Action Plans	Short term (2025- 2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
Procure complementary technologies and solutions				
Establish standards and certifications for carbon dioxide removal				
Consider CO_2 removal technology or technology-based CO_2 removal (CDR) in the legal framework				

Legend:

Immediate Urgency	Moderate Urgency	Low Urgency

***Source*:** Authors

Strategy 5: Facilitate CCS hubs and international transboundary CO_2 transportation

To facilitate CCS hubs and international transboundary CO_2 transportation, the immediate urgency in the short term (market creation phase) is to **establish a capture and storage database** with a mutually agreed methodology to map potential source and sink locations. This database should include geological data, capture/storage capacity, and other standardised necessary data. Establishing this database is crucial as it provides a foundation for regional and site-specific screening, ensuring that the most suitable locations are identified for CCS hubs. It also supports detailed site selection and characterisation, which are essential for effective source-sink match modelling and assessing transportation and accessibility requirements. The Ministry of Energy and Mineral Resources will oversee this process, leveraging their expertise in managing geological data. R&D centres will provide scientific and technical expertise to ensure the accuracy and comprehensiveness of the database.

Once the source-sink locations are mapped and modelled, the region needs to **regulate access to shared transport and storage infrastructure, cross-border CO_2 transportation, and compliance with international law for cross-border CO_2 transport activities**. This regulation should begin in the short term (market creation phase) and continue into the mid-term (market growth phase). Regulating access and ensuring compliance help manage the logistics of CO_2 transportation and storage, ensuring that all activities are conducted safely and legally. The Ministry of Public Works will be responsible for the planning and construction of the necessary infrastructure for CO_2 transport, such as pipelines. The Ministry of Environment will oversee the environmental impacts and ensure compliance with environmental laws. Starting this regulation early ensures a smooth transition from planning to implementation. R&D centres will support this process by providing ongoing R&D to optimise transportation and storage technologies.

From the mid-term to the long-term (market mature phase), the region needs to establish **close coordination to prevent disputes across international borders and avoid overlaps between multiple frameworks across jurisdictions**, potentially managed by the Ministry of Energy and Mineral Resources. This coordination is necessary to maintain a stable and cooperative environment for CCS operations, contributing to the long-term success of the initiative. It ensures that all parties involved in CCS activities are aligned and that there is a clear understanding of their roles and responsibilities.

Table 7.5 Action plans and timeline: Facilitating CCS hubs and international transboundary CO_2 transportation

Action Plans	Short term (2025- 2030)	Mid-term (2031-2040)	Long term (2041-2050)	Stakeholders
	Phase 1: Market Creation	Phase 2: Market Growth	Phase 3: Market Mature	
Close coordination to prevent disputes across international borders and overlap between multiple frameworks between jurisdictions				• Ministry of Energy and Mineral Resource • R&D Centres • Ministry of Public Works • Ministry of Environment
Regulate access to the shared transport and storage infrastructure				
Regulate the cross-border CO_2 transport				
Achieve compliance with international law for cross-border CO_2 transport activity				
Establish a capture and storage database with a				

Action Plans	Short term (2025- 2030) Phase 1: Market Creation	Mid-term (2031-2040) Phase 2: Market Growth	Long term (2041-2050) Phase 3: Market Mature	Stakeholders
mutually agreed methodology to map the potential source and sink location				
Conduct regional and site-specific screenings to uncover additional source and sink opportunities				
Conduct site selection with detailed characterisation to support source-sink match modelling to assess transportation and accessibility requirements				

Legend:

Immediate Urgency	Moderate Urgency	Low Urgency

***Source*:** Authors

7.3 Way Forward

To accelerate the deployment of CCS technologies in ASEAN, the region must implement several key action plans to mitigate the primary challenges of CCS development. Analytical findings suggest that ASEAN needs to focus on improving key parameters related to the three pillars of CCS deployment: policy, legal and regulatory framework and storage.

A significant factor contributing to the challenges of financial and economic viability in the region is the high cost of CCS projects. To address this, immediate and urgent action plans are required. These include providing financial support through the acceleration of carbon pricing mechanisms, subsidies, and the implementation of favourable contracts and procurement processes. These measures aim to reduce the overall cost of CCS projects, thereby enhancing their competitiveness compared to other carbon reduction technologies.

The readiness of supportive policy and regulatory frameworks for CCS projects in ASEAN remains limited. Currently, only Indonesia and Sarawak have specific regulations governing CCS projects. These existing frameworks can serve as valuable examples for other ASEAN Member States (AMS) in developing their legal and regulatory structures for CCS. However, the frameworks in Indonesia and Sarawak can still be improved by addressing additional parameters, such as industrial regulations, environmental impact assessments, carbon storage assessment methodologies, transboundary emissions, and specific industrial regulations related to CCS.

The methods applied for assessing potential CO2 sources and sinks require urgent attention. This effort should be complemented by establishing a comprehensive database of carbon storage sites, which would facilitate collaboration among the AMS in developing CCS hub infrastructure across the region. The involvement of state-owned and private companies operating in relevant sectors, such as oil and gas, will be crucial in these efforts.

Finally, the establishment of a CCS Working Group consisting of relevant stakeholders from across ASEAN is a timely and significant step towards accelerating CCS deployment in the region. This group would play a key role in fostering regional collaboration, knowledge sharing, and capacity building, while also seeking international support from dialogue partners. The Working Group would ensure that the necessary actions are taken to develop a robust and comprehensive framework for CCS deployment, helping ASEAN transition from early-stage CCS projects to mature, commercial-scale operations.

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Appendix

Summary of key questions used in the questionnaire

No	Parameter		Key questions
1.	Key challenges	a.	What is the priority ranking of of the **common challenges** in CCS/CCUS projects (**technological readiness, economic viability, project design and financing availability**) based on its impact on **project development** in ASEAN?
		b.	What is the priority ranking of the **project risks** in CCS/CCUS projects (**legal and regulatory risk, scope creep risk, social and political risk, natural hazard risk, performance risk, technology risk, market risk and resource risk**) based on the impact on **project implementation** in ASEAN?
		c.	What is the priority ranking of the **common challenges** in CCS/CCUS project development (**technology readiness, economic viability, project design and financing availability**) based on the relative **urgency** that it be addressed to mitigate project risks during the implementation phase in ASEAN?
2.	High-level policy development	a.	What is the priority ranking of the **policy approaches** (**incentive or penalty approach, shared cost allocation approach and full control approach**) based on their suitability to the objective of promoting CCS/CCUS project development and implementation in ASEAN?
		b.	What is the priority ranking of the **policies** (**industrial regulations, strategic signalling for investors, upfront cost incentives and performance-based incentives**) based on their implementation maturity level in ASEAN?
		c.	What is the priority ranking of the following **policies** (**industrial regulations, strategic signalling for investors, upfront cost incentives and performance-based incentives**) based on their **urgency** of adoption (if not yet adopted) or refinement (if already adopted) in the next 3 to 5 years in ASEAN?
		d.	What is the priority ranking of the following **policies** (**industrial regulations, strategic signalling for investors, upfront cost incentives and performance-based incentives**) based on their **influence** on the overall economic viability of the CCS/CCUS projects in ASEAN?
3.	Legal and regulatory development	a.	What is the rate of the current **linkage** between legislation and regulation of CCS/CCUS with the **broader** legislation and regulation of the energy sector on the scale of 1 (non-existent or very weak linkage) to 5 (very strong linkage)?
		b.	What is the priority ranking of the following **elements** of CCS/CCUS in terms of their **coverage** within the existing legal and regulatory framework in ASEAN?
		c.	What is the priority ranking of the following **challenges** based on their **potential to bottleneck** CCS/CCUS project development and implementation in ASEAN?
		d.	What is the priority ranking of the following **emerging factors** based on their **likelihood to hinder** CCS/CCUS project development and implementation in the near future in ASEAN?
4.	Storage and technical aspects	a.	What is the priority ranking of the following **factors** based on their **urgency** to be addressed/evaluated?
		b.	What is the priority ranking of the following **accessibility aspects** of the CO_2 sources based on their **role** in facilitating/enabling the CCS/CCUS hub?
		c.	What is the priority ranking of the following **factors** based on their **role** in addressing the long-term liability of geological CO_2 **storage?**
		d.	What is the priority ranking of the following **factors** based on their **role** in facilitating/enabling the sustainability of CO_2 **utilisation** sites?

Source: Compiled by the authors

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