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Gap Analysis and Key Enabling Factors for Carbon Capture Utilization and Storage development in Thailand Oil and Gas Industry to Achieve Carbon Neutrality Target

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To achieve the carbon neutrality of the country, Thailand plans to implement carbon capture, utilization, and storage (CCUS) technology to capture 40 million t CO_2 from the energy industry and selected industrial sectors by 2050. However, due to the very high cost of CCUS, mainly from the capturing process, may hinder the pathway to meet the target. This paper discusses the new demand for CCUS development in Thailand specifically in the oil and gas industry from both domestic exploration and production (E&P) units and refinery plant, including the current development status analysis. Institutional and regulatory framework of the country are well raised along with the economical business model and criteria to accelerate the sustained CCUS deployment. From the real-world assessment, we found that the natural gas production industry has the potential to reduce from the E&P industry and oil refinery plants by between 8.22 – 50.59 Mt/y and 9.79 Mt/y, respectively. Gap analysis have been assessed in the context of policy, regulatory, financial business model, technology and capacity building with recommendation and relevance data. The prospective business model should consider the following criteria: source-sink matching, technology cost from capture to storage with subsidization model, best available technology, and time period to adopt the technology.

1. Introduction

Thailand started her first long-term nationally appropriate mitigation action (NAMA) greenhouse gas (GHG) mitigation and performance tracking since 2013 (Wongsapai et al, 2017). In recent decades, CCUS technology has gained widespread recognition as a promising approach to substantially reducing GHG emissions (Zhang et al, 2019). In 2015, the Paris Agreement marked a significant milestone in global efforts to combat climate change by striving to limit temperature increases to below 2 degrees Celsius (Cristiu et al, 2022). The process begins with countries setting goals to mitigate their emissions, followed by the adoption of carbon neutrality targets, and ultimately culminates in the achievement of net-zero targets. Thailand is one of those seeking viable methods to achieve a goal that has been specified across three timeframes: short, medium, and long term. The goal is to achieve a capacity of 10 million metric tons per annum (Mt/y) by 2030, 40 Mt/y by 2050, with the aim of facilitating carbon neutrality, and reaching a capacity of 60 Mt/y by 2065, aligning with the net-zero target, (Modified from Thailand LT-LEDS (ONEP, 2022b)). Carbon capture, utilization and storage (CCUS) technology has been extensively debated and recognized as a vital tool for achieving this objective. However, Thailand still lacks concrete studies and applications of CCUS in pilot industries. Notably, the initial phase of studying pilot industries is appropriate for investigating the potential for effective application of CCUS technology. This research is intended to prioritize industries and subsequently select the most suitable industry to install CCUS technology. Geological potential area criteria are also considered. The selected industry can be a part of Thailand's mitigation measures for achieving the carbon neutrality target.

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2. Methodology

This research aims to study on gap analysis and key enablers within Thailand's oil and gas industry to achieve carbon neutrality targets for both the exploration and production industry (E&P) and the refining industry, integrating carbon capture and storage (CCS) technologies. The study will be based on two criteria: impact and readiness. The impact criteria use CO_2 emission data from Office of Natural Resources and Environmental Policy and Planning Thailand (ONEP) to screen high-impact industries. Then the industry that was initially selected will be assessed for suitability using the readiness criteria.
Additionally, the research will offer an estimated overview of the potential targeted industry capture, considering the appropriate source to sink matching of the target industry. CCS technology holds particular significance due to the capture process, which constitutes approximately 60 – 70 % (ETC, 2022) of the primary cost associated with CCS implementation. As a result, the selection of industry groups assumes a critical role in assessing the feasibility of CCS implementation.

2.1 Criteria for sector prioritization

In Table 1, there are two impact sub-criteria. The first one is the intensity of CO_2 emissions, which is at a high level (1.1). The second one is the CO_2 emitting source, which is a stationary source (1.2). Upon reviewing the data provided in BUR4 (ONEP, 2022a), it was revealed that industries in the energy sector and industrial processes and product use (IPPU) exhibit a substantial proportion of CO_2 emissions. Table 1 presents the weighted assessment of these industries based on the defined criteria. Several industries qualify as Criterion 1 industries and can be weighted accordingly. These industries include electricity and heat generation (1A1a), petroleum refining (1A1b), manufacturing and construction (1A2), cement industry (2A1), and chemical industry, and ethylene production (2B8b).

Table 1: CO_2 emissions from inventories in 2019 of industry groups achieving impact criteria.

IPCC Sectors	CO_2 emission		sub-criterion		Results
	($MtCO_2$)	(%)	1.1	1.2	
1.Energy (1A1,1A2,1A3 and 1-Others)	244.99	87.80			
1A1 Energy industries (1A1a and 1A1b)	102.44	36.71			
1A1a Electricity and heat production	92.99	33.32	✓	✓	*(1A1a)
1A1b Petroleum refining	9.45	3.39	✓	✓	*(1A1b)
1A2 Manufacturing industries and construction	52.23	18.72	✓	✓	*(1A2)
1A3 Transport	75.23	26.96	✓		
1-Others	15.09	5.41			
2. IPPU (2A, 2B, 2C and 2-Others)	32.38	11.60			
2A Mineral industry (2A1 and 2A-Others)	19.40	6.95			
2A1 Cement production	18.47	6.62	✓	✓	*(2A1)
2A-Others	0.93	0.33			
2B Chemical industry (2B8b and 2B-Others)	12.36	4.43			
2B8b Ethylene	10.98	3.93	✓	✓	*(2B8b)
2B-Others	1.38	0.49			
2C Metal production	0.34	0.12		✓	
2-Others	0.28	0.10			
3. Agriculture	1.51	0.54			
4. LULUCF					
5. Waste	0.16	0.06			
Total of CO_2 emission (1, 2, 3, 5)	279.04	100			

The readiness criteria comprise four sub-criteria; the first sub-criterion, labeled as 2.1, focuses on industries with a sufficient technology readiness level (TRL) for the business or commercial application of CO_2 capture technology. The second sub-criterion, labeled as 2.2, considers industries with geological storage potential or those that hold promise as CO_2 utilization targets. The third sub-criterion, labeled as 2.3, considers industries that have conducted an analysis of their CO_2 emission data and have published their findings using reliable resources. The fourth sub-criterion, labeled as 2.4, focuses on industries that possess rich data on domestic and worldwide GHG mitigation costs.
Among the CCS-applicable industries, the petroleum refining sector (1A1b) demonstrated the highest potential with total score of 88. It was closely followed by the power and heat production sector (1A1a) with total score of

78, and the cement manufacturing sector (2A1) with a score of 65. It is noteworthy that while the refining industry may have scored lower on the impact criteria, it performed well on the readiness criteria, as shown in Table 2.

Table 2: Priorities for CCS-applicable industries

Criteria for priorities	Share (%)	Sectors 1A1a	1A1b	1A2	2A1	2B8b
Impact Criteria						
(1.1) High levels of CO_2 emissions	20	20	8	16	12	8
(1.2) Stationary sources of CO_2 emissions	10	10	10	10	10	10
Readiness Criteria						
(2.1) Sufficient technology readiness level (TRL) for the business or commercial	20	16	20	4	12	8
(2.2) Geological storage potential or utilization targets	20	8	20	8	16	16
(2.3) Published their findings using reliable resources.	15	12	15	6	6	6
(2.4) Possess rich data on domestic and worldwide GHG mitigation costs	15	12	15	3	9	9
Total	100	78	88	47	65	57

2.2 Oil and gas production and refinery in Thailand

Oil refineries are part of the downstream sector in the petroleum industry, whereas the potential for effective application of CCS technology extends beyond just the downstream sector. CCS can also be applied in the upstream sector, specifically in Exploration and Production (E&P) related activities. Figure 1 presents production data for crude oil, natural gas, and oil refining (EPPO, 2023), providing insights into the production trends in these sectors. According to the 2022 statistics, crude oil production amounted to 78,853 barrels/d, while natural gas production reached 2,648 MMSCFD. The refining sector exhibited an increase in production statistics. The average growth rate of the industry can be divided into three distinct periods. Firstly, from 1986 – 1997, the average growth rate was recorded at 15 %. Secondly, from 1998 – 2018, the growth rate were relatively low at 2 %. Lastly, during the period of 2019 (impacted by the COVID-19 pandemic) – 2022, the average growth rate experienced a negative trend of 1.6 %, due to the pandemic and also the decline domestic resources.

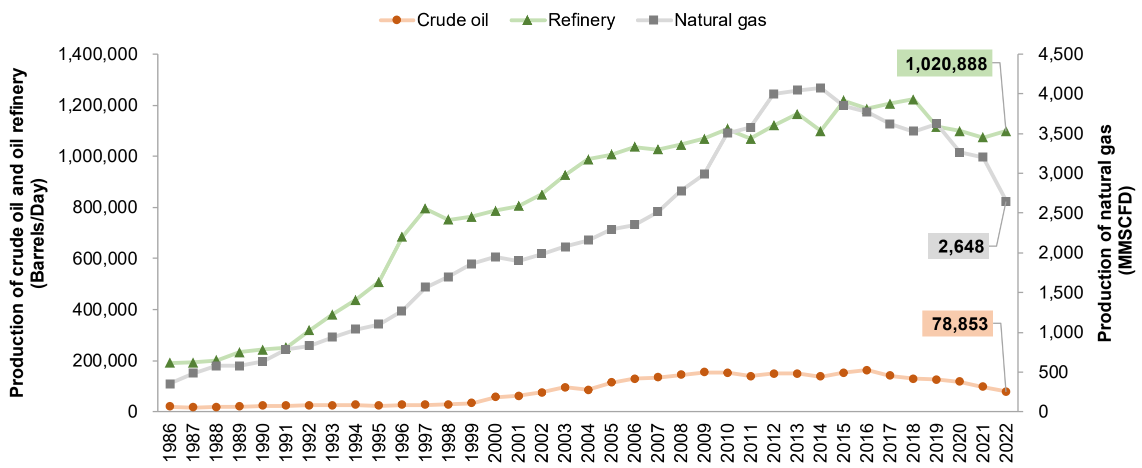

Figure 1: Production of the oil & gas industry in Thailand (1986 – 2022)

3. Results and discussions

3.1 Potential applications for CCS in the target industry

Thailand has taken the initiative to study and develop CCS projects within the country. One notable pilot project is the Arthit CCS project, located in the Gulf of Thailand. The project focuses on carbon sequestration, with a projected potential of 1 Mt/y for carbon storage (Global CCS institute, 2022). The study is anticipated to be concluded and operational by mid – 2024. The 13-source data is collected to determine the potential of CCS of the E&P industry based on natural gas production from 2022. The CO_2 emission data is determined by the specific emission factor of 0.0551 tCO_2/MCF (EPA, 2023). CCS can implement using membrane technology, with efficiency of capture rate of 95 % (Ji and Zhao, 2017), resulting in a potential capture volume of approximately 50.59 Mt/y. Considering the production volumes, the natural gas fields of Bongkot account for 19.18 %, followed by JDA at 17.22 %. The Arthit source also exhibits a significant potential of 12.16 %. To initiate actual operations, it is essential to determine the feasible capture and containment quantities. In this regard, it is crucial to reference the Arthit CCS Project pilot field, which has a capacity of 1 Mt/y. Upon comparing this pilot project with the natural gas fields, it becomes evident that all the natural gas fields have the potential to function as pilot sources, collectively possessing an estimated capacity of approximately 8.22 Mt/y. The details are in Table 3.

Table 3: Potential applications for CCS in E&P industry

Number	Natural gas source	Natural gas production (The data year 2022)		CO_2 emission	Potential for CCS		
					Overall		Arthit source ref.
		A	B; (A*1,000*365)	C; (B*0.0551)	D; (C*95 %)		E; ((1.00*D)/D_{Arthit})
	(Unit)	(MMCF/d)	(MCF/y)	(tCO_2/y)	(Mt/y)	(%)	(Mt/y)
1	Bongkot	508	185,420,000	10,216,642	9.71	19.18	1.58
2	JDA	456	166,440,000	9,170,844	8.71	17.22	1.42
3	Pailin	432	157,680,000	8,688,168	8.25	16.31	1.34
4	Bongkot Tai	402	146,730,000	8,084,823	7.68	15.18	1.25
5	Arthit	322	117,530,000	6,475,903	6.15	12.16	1.00
6	Erawan	311	113,515,000	6,254,677	5.94	11.74	0.97
7	Phu horm	97	35,405,000	1,950,816	1.85	3.66	0.30
8	Tan tawan	59	21,535,000	1,186,579	1.13	2.23	0.18
9	Sirikit	27	9,855,000	543,011	0.52	1.02	0.08
10	Others	19	6,935,000	382,119	0.36	0.72	0.06
11	Nam phong	8	2,920,000	160,892	0.15	0.30	0.02
12	Jasmine	6	2,190,000	120,669	0.11	0.23	0.02
13	Yoong thong	1	365,000	20,112	0.02	0.04	0.00
Total		2,648	966,520,000	53,255,252	50.59	100	8.22

Remark: Operation day 365 d/y

Correlation between oil refining volume and CO_2 emissions (Madugula et al, 2021) as shown in Figure 2a, there is a strong linear relationship (R^2 = 0.9640) The data has been plotted using the oil refining production over 18 y, specifically from 2000 – 2017, incorporating data from all six refineries in Thailand (EPPO). Consequently, a simple linear regression equation was derived between the transformed total operable refining capacity (X) and transformed CO_2 emissions (Y), resulting in the equation Y = 0.0325X – 2867.2.
Based on the 2022 data from the aforementioned six refineries (EPPO), Figure 2(b) illustrates the potential of CCS in the oil refining industry. It can be implemented using amine technology, with an efficiency of capture rate of 98 % (Lee et al, 2020) resulting in a potential capture volume of approximately 9.79 Mt/y.

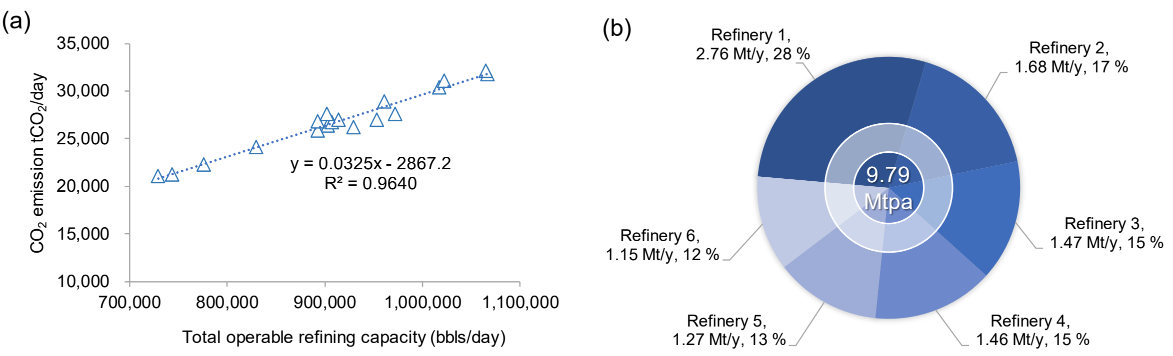

Figure 2: (a) Linear regression equation, and (b) Share of potential for CCS in six oil refinery plants.

4. Sink – Source matching

Sink-source matching focus on identifying potential sources of CO_2 emissions. This matching process involves considering various factors such as proximity, scale, capacity, and compatibility between the emission source and the sink facility. Some common criteria for sink-source matching include Proximity, Scale and Capacity, Compatibility, Cost-effectiveness, and Regulatory and Policy Framework.

4.1 Result of Sink – Source matching

The implementation of CCS requires careful consideration of reservoir capacity, specifically its ability to store significant amounts of CO_2. In Thailand, several regions, particularly those in the Gulf of Thailand, have been identified as having suitable storage capacity for CO_2 (Choomkong et al, 2017). The six oil refineries in Thailand are geographically clustered in neighboring zones, primarily located near the coast of the Gulf of Thailand, as depicted in Figure 3. Considering the refining industry's need for a suitable CO_2 reservoir for CCS, the North Gulf of Thailand emerges as the targeted area. This region is estimated to have a storage capacity of approximately 7,000 Mt CO_2, making it a promising site for CCS implementation within the refining sector.

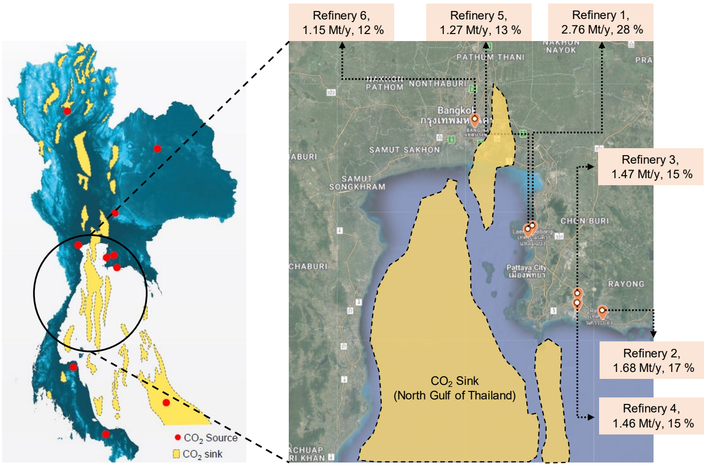

Figure 3: Source – Sink matching suitable for oil refining in Thailand (Modified from PTTEP, 2023).

5. Gap Analysis and policy recommendations

The main gaps in the implementation of CCS in Thailand consists of the absence of a comprehensive policy and regulatory framework specifically tailored to CCS (Muslemani et al, 2020). Another crucial gap is the limited availability of suitable technological infrastructure for CCS. This includes the lack of carbon capture technologies, storage sites, and transportation networks for captured CO_2. Insufficient funding and limited financial mechanisms pose significant barriers to CCS implementation in Thailand. While there are existing funding schemes for renewable energy projects, similar mechanisms for CCS projects are lacking. The gap in public awareness and engagement about CCS hampers its acceptance and implementation. A lack of specialized skills and knowledge in CCS technologies is another significant gap. Building capacity among researchers, engineers, and policymakers is crucial for long-term successful CCS implementation.

There are many sectors, both public and private, relate in CCS driving, as shown in Figure 4. The main sector is the government with the main function being to support the industry sector through regulations and guidelines that facilitate financing, providing important guarantees for entrepreneurs, followed by private sector interested in investing in CCS businesses in Thailand.

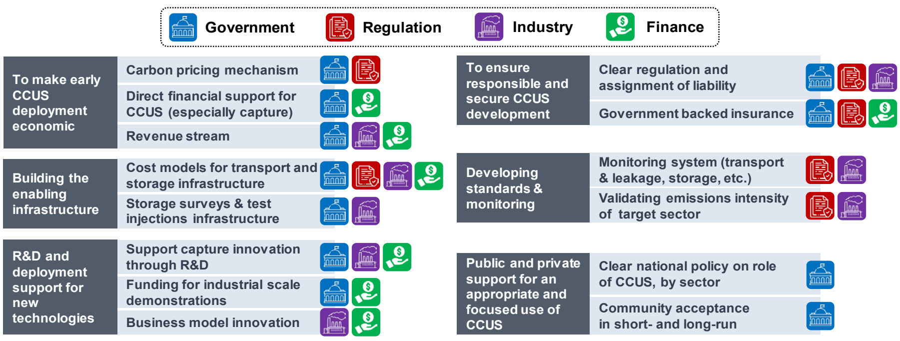

Figure 4: Policy recommendation for CCS adoption in Thailand (Modified from ETC, 2022).

6. Conclusions

Geology and petroleum engineering skills provide the E&P business with an edge. This skill is essential for CCS growth, creating a new economic opportunity that could potentially replace industrial processes. The membrane technique can capture 95 % of natural gas emissions from fields at 50.59 Mt/y and 8.22 Mt/y, making them suitable pilot sources. The Amine technique, with a capture efficiency of 98 %, could potentially capture 9.79 Mt/y in the oil refining business. The refining sector requires a CO_2 reservoir for CCS, and thus the North Gulf of Thailand is being considered as the target area. This region could potentially host CCS for the refining sector due to its 7,000 $MtCO_2$ storage capacity. The key issues identified in the implementation of CCS in Thailand are policy and regulatory framework, technological infrastructure, financial mechanisms, public engagement, and capacity building. It is suggested that government must act immediately and strongly to resolve these problems. Especially financial issues of source-sink matching will be key for the investment business model.

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