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Economic Viability and Policy Imperatives of Carbon Capture, Utilisation and Storage in Indonesia's Pathway to Net-Zero Emissions

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Abstract: Anthropogenic climate change, driven primarily by the intensification of greenhouse gas emissions since the Industrial Revolution, continues to pose significant environmental and socio-economic challenges. Among the most promising mitigation strategies is carbon capture, utilisation and storage (CCUS), which facilitates the reduction of carbon dioxide (CO_2) emissions by capturing CO_2 from large point sources and storing it in geological formations, such as depleted oil and gas reservoirs. In some configurations, CCUS has also been employed to enhance hydrocarbon recovery. While the technology is widely recognised for its potential to contribute to decarbonisation goals, particularly in fossil fuel-dependent economies, its large-scale deployment remains constrained by considerable economic and regulatory barriers. In Indonesia, a country with ambitious commitments to achieve net-zero emissions by 2060 but a continued reliance on fossil energy, CCUS is increasingly being considered a strategic pathway for transitioning the energy sector toward sustainability. This study undertakes a systematic review of existing and near-operational CCUS initiatives globally, with a focus on economic performance, cost structures, and policy frameworks. Evidence from the literature suggests that although CO_2-enhanced oil recovery (CO_2-EOR) can yield short-term productivity gains, the high capital and operational expenditures associated with CCUS systems often undermine their economic feasibility in the absence of supportive policy instruments or carbon pricing mechanisms. Furthermore, the lack of integrated regulatory frameworks and stakeholder coordination has been identified as a critical barrier to progress in Indonesia. It is therefore argued that a comprehensive national strategy is required—one that aligns with Article 6 of the Paris Agreement and incorporates targeted subsidies, regulatory clarity, and inter-sectoral collaboration among emitters and storage providers. The analysis underscores the necessity of embedding CCUS into Indonesia's long-term decarbonisation roadmap through an approach that balances environmental obligations with economic pragmatism.

Keywords: Carbon capture, utilisation and storage (CCUS); Climate change mitigation; Net-zero emissions; Energy policy; Environmental economics

1. Introduction

Fossil fuels have historically served as a primary energy source despite being finite resources (Jiang et al., 2022; Pambudi et al., 2023). Climate change worsening has been a worldwide issue for the past few decades (Talebian et al., 2023). Countries around the world were beginning to recognize that without substantial focus, the capacity of nature to sustain human existence would persist in diminishing (Kaddo, 2016; Leo et al., 2024). From the onset of the industrialization period, there has been a growing demand for fuel sourced from fossil fuels (Janzen et al., 2020).

Fossil fuel consumption results in the generation of greenhouse gases, leading to a rise in the global temperature. Since the pre-industrial era, the Earth's temperature has increased by 1.1℃, and it is projected to surpass 1.5℃ within the next 1-5 years. The increase in worldwide temperatures is resulting in damage to both the ecosystem and the survival of humans. This includes higher sea levels, widespread extinction of species, scarcity of food, and increased prevalence of contagious illnesses (Wahyuni et al., 2023), and clean water shortages (Abdelzaher et al., 2020; Karuniasa & Pambudi, 2022).

International agreements started in 1988 when the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). In 1992, the United Nations established the United Nations Framework Convention on Climate Change (UNFCCC), followed by the introduction of the Kyoto Protocol in 1997. This cooperative action was intended to tackle the problem of climate change caused by the release of greenhouse gases. The Kyoto Protocol mandates that developed countries reduce their emissions while also urging developing nations to participate in similar initiatives. The global agreement was improved in 2015 with the Paris Agreement, which assigns different emission reduction responsibilities to each country based on their capabilities. Therefore, both industrial and developing nations are required to make efforts to decrease emissions (United Nations, 2015).

Indonesia, as a sizable country with a firm dedication to preserving the environment and promoting sustainable growth, demonstrated its dedication by officially agreeing to the terms of the Paris Agreement in 2016 (Presiden Republik Indonesia, 2016). Indonesia's government announced its goal of reaching net zero emissions by 2060 and established a reduction target for emissions by 2030 in the Enhanced Nationally Determined Contributions (NDC) document (United Nations Climate Change, 2022).

The NDC is divided into five sectoral categories, including Energy, Waste, IPPU (Industrial Process and Production Use), Agriculture, and FOLU (Forestry and Other Land Uses), with specific emission reduction targets outlined in Table 1 and Table 2.

Table 1. Indonesia’s enhanced NDC—Emission reduction target

Sector	GHG Emission Level 2010* (Mton CO_2eq)	GHG Emission Level 2030 (Mton CO_2eq)			GHG Emission Reduction			
					Mton CO_2eq		% of Total BAU	
		BAU	CM1	CM2	CM1	CM2	CM1	CM2
Energy*	453.2	1,669	1,311	1,223	358	446	12.5	15.5
Waste	88	296	256	253	40	43.5	1.4	1.5
IPPU	36	69.6	63	61	7	9	0.2	0.3
Agriculture	110.5	119.66	110	108	10	12	0.3	0.4
Forestry and Other Land Uses (FOLU)**	647	714	214	-15	500	729	17.4	25.4
Total	1,334	2,869	1,953	1,632	915	1,240	31.89	43.20

Notes: CM1= Counter Measure 1 (unconditional mitigation scenario), CM2= Counter Measure 2 (conditional mitigation scenario), *including fugitive, **including emissions from estate and timber plantation

Table 2. Indonesia’s enhanced NDC—Average growth

Sector	Annual Average Growth BAU (2010-2030)	Average Growth 2000-2012
Energy*	6.7%	4.5%
Waste	6.3%	4.0%
IPPU	3.4%	0.1%
Agriculture	0.4%	1.3%
FOLU**	0.5%	2.7%
Total	3.9%	3.2%

Table 1 illustrates that over 35% of the emission reduction goal outlined in the NDC is attributed to the energy industry. Therefore, it is essential to focus on this sector. CCUS is acknowledged as a strategy to reduce emissions in the energy sector, in addition to energy efficiency and renewable energy sources (Leonzio et al., 2020a).

CCUS is a method used to capture CO_2 emissions, which can then be used to enhance the production of oil and gas, before being stored in an underground geological location (Xie et al., 2014). Carbon Capture and Storage (CCS) refers to a project where CO_2 is stored underground in geological formations instead of being utilized to enhance oil and gas production. CCUS is considered to be a potential solution for reaching decarbonization goals (Talebian et al., 2023). CCUS has the capacity to lower carbon dioxide emissions by as much as 32% by 2050, potentially assisting Indonesia in reaching its NDC goal. Failure to address this issue could result in a 138% rise in the cost of emissions reduction (Leonzio et al., 2020a).

CCUS plays an essential role in cutting emissions, but it encounters significant obstacles due to the high costs and limited revenue generated by extra oil and gas production (Nunes et al., 2021). In order to facilitate widespread implementation of CCUS activities, developing a thorough solution and conducting detailed research on the economic factors of CCUS investments is crucial.

As a country that has ratified the Paris Agreement through Law No. 16/2016, Indonesia targets Net Zero Emission by 2060 and has set a conditional 43.2% emission reduction target by 2030. The energy sector contributes more than 35% to the total emission reduction target in the NDC, making this sector very strategic. CCUS is recognized in the NDC document as one of the energy sector decarbonization solutions, in addition to energy efficiency and renewable energy utilization.

Despite its great potential to reduce emissions by 32% by 2050, the implementation of CCUS in Indonesia still faces major challenges, especially in terms of economics. One of the research gaps addressed in this study is why CCUS is not yet economically viable in Indonesia, despite its significant potential. The main challenge lies in the high initial investment cost and low potential revenue from CO_2 utilization, especially in boosting oil and gas production. Unlike developed countries that already have incentive mechanisms such as carbon trading or fiscal incentives, Indonesia still lacks sufficient policy and regulatory support to encourage CCUS investment. In addition, the absence of an effective carbon pricing system and limited carbon storage infrastructure exacerbate the economics of CCUS projects in Indonesia.

Therefore, this research seeks to address this gap by analyzing the factors that influence the economic sustainability of CCUS projects and formulating alternative policy and financing approaches that can be applied to encourage the implementation of CCUS in the Indonesian context, in order to support the achievement of NDC targets and commitments to the Paris Agreement. The focus of this research is to determine the different elements that influence the economic sustainability of CCUS initiatives and investigate methods to improve their financial viability in Indonesia. Additionally, drawing from the experiences of other countries in CCUS initiatives, this review aims to offer suggestions for the successful implementation of CCUS projects in the Indonesian setting.

2. Methodology

The article utilized a systematic literature review approach to locate pertinent literature regarding the economic aspects of CCUS, selecting suitable scientific papers for analysis. The foundation of the Systematic Literature Review was built upon bibliometrics. The purpose of utilizing Systematic Literature Reviews is to offer a thorough understanding of the latest research landscape and the potential implications that can be drawn from it (Feak & Swales, 2009).

The study conducted a thorough examination of existing literature in two separate stages: firstly, by sifting through fundamental papers indexed in Scopus using specified keywords, and subsequently, by conducting a Bibliometric Analysis utilizing VOSViewers software. The utilization of bibliometric analysis entails utilizing numerical data to illustrate connections among articles, keywords, journals, citations, and co-citation networks. VOSviewer assists in creating maps and presenting them in diverse manners, with each highlighting a distinct facet of the mapping tool (Van Eck & Waltman, 2010). Scopus was selected because it is considered the widest-reaching database available.

The initial phase of the research commenced with a thorough examination of scholarly articles in Scopus utilizing specific keywords such as "CCUS", "Cost", and "Economic", yielding a total of 218 articles. Subsequently, a Bibliometric Analysis was conducted using VOSviewer, employing co-occurrence as the chosen type of analysis for all keywords and setting a minimum occurrence threshold of 30 to highlight pertinent keywords. Through this methodological approach, it was determined that 19 keywords out of a pool of 2532 satisfied the established threshold for significance.

2.1 VOS Viewer and Bibliometric Analysis

The first observation can be seen in Figure 1, which displays the network visualization featuring the subjects with the most connections. This visual representation reveals three distinct groups that demonstrate the relationships between key concepts in CCUS economic discussions. These clusters include: (1) carbon dioxide, carbon capture, CCUS, and cost. (2) carbon storage, carbon utilization, and economic analysis. (3) Greenhouse Gas, Emission Control, Gas Emissions, and Investment.

In Figure 1, it can be seen that the keywords in CCUS research fall into three main groups, marked in red, green, and blue. The red group focuses on the issues of carbon dioxide, costs, CCUS, and economic and social effects, reflecting the attention to the economic and social aspects of CCUS technology implementation. The green group groups terms such as carbon capture, carbon utilization, and carbon storage, which relate to the technical aspects of these technologies. Meanwhile, the blue group includes topics such as greenhouse gases, climate change, and gas emissions, indicating the close connection between CCUS and global climate change mitigation efforts.

Afterward, Figure 2 demonstrates the following trends: 1) In the past four years, scholars predominantly addressed topics such as greenhouse gases, enhanced recovery, and cost-benefit analysis related to injecting CO_2 for oil & gas enhanced recovery. 2) Between 2020 and 2021, there has been a shift in focus towards topics like Carbon Dioxide, Carbon Capture, CCUS, and emission control among scholars. 3) Starting from 2022 up to the present time, the discourse in studies has revolved around carbon storage, carbon utilization, and economic analysis. These developments indicate that the economic dimensions of CCUS technologies are beginning to take center stage in decision-making and sustainability studies of these technologies. Yellow to blue colors indicate the year of publication, where terms such as economic analysis, CCUS, and carbon storage are colored yellow-green, indicating that these topics are relatively new concerns in the literature. This indicates that in recent years, the focus of research has shifted from the technical side towards the economic and policy sustainability of CCUS technologies.

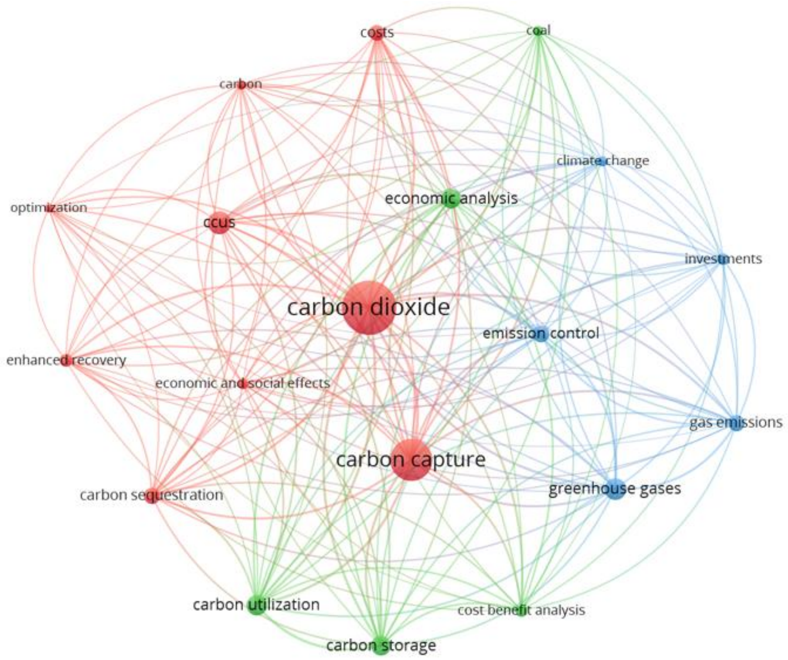

Figure 1. Network visualization

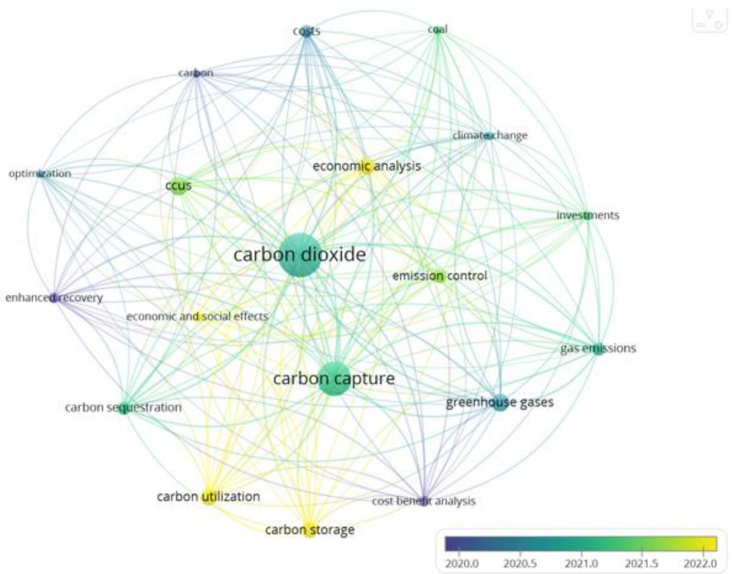

Figure 2. Overlay visualization

Figure 3 shows the density visualization of seven key topics like Carbon Dioxide, Carbon capture, CCUS, Carbon Utilization, Emission control, and Economic Analysis. The red color indicates the most frequently researched areas, such as carbon dioxide and carbon capture, which are the core of CCUS technology. Topics such as cost-benefit analysis, carbon utilization, and carbon storage are in the green area, indicating that while important, these areas are not as prevalent as other key topics and are still open for further exploration.

Overall, the results of this analysis show that CCUS research is distributed across three main foci: technical, economic and environmental. The emergence of economic topics in the latest trends indicates that economics is key to policy-making and adoption of this technology in various countries, including Indonesia.

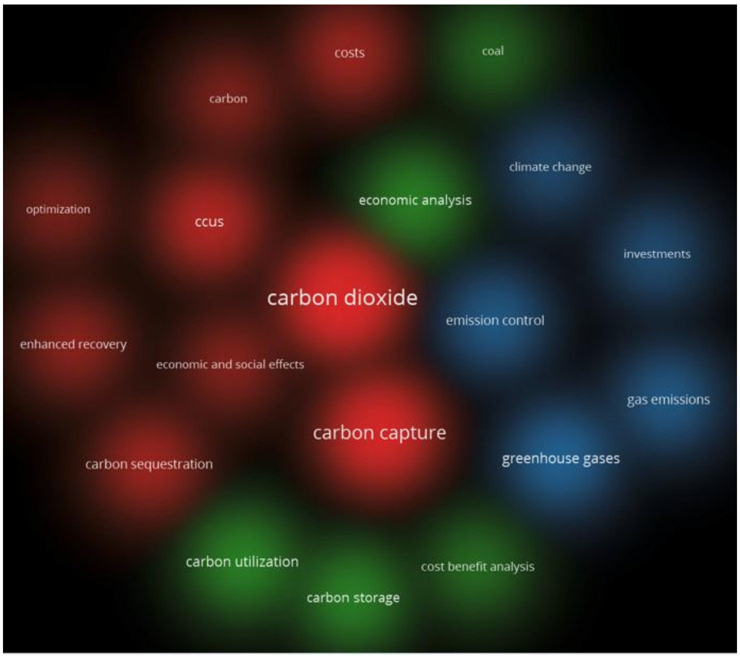

Figure 3. Density visualization

2.2 Study Selection Process

The study began with a Bibliometric Analysis, then progressed to a Systematic Literature Review to answer the research questions and make conclusions on the subject matter. The process of selecting studies (Figure 4) in the study is outlined as such:

1) Keywords: Describing the findings of the Bibliometric study, which was divided into two stages. The initial step of the research involved choosing papers from Scopus that focused on Environmental keywords, like greenhouse gas, emission control, and climate change. This process revealed a total of 19,927 papers. In the next stage, additional criteria were applied, including techno-economic factors such as carbon dioxide, enhanced recovery, and CCUS. As a result, the number of papers was reduced significantly to only 52.
2) Title Review: The review did not consider topics outside the research scope such as geology, hydrogen, chemical industry, public perception, and fluid dynamics. As a result, 17 papers were removed, leaving a list of 35 papers.
3) Abstract Review by excluding elements that did not align with the focus of the research, such as focusing solely on capturing and/or storing without utilization. This screening process led to the elimination of 11 additional papers, leaving a total of 24 papers.

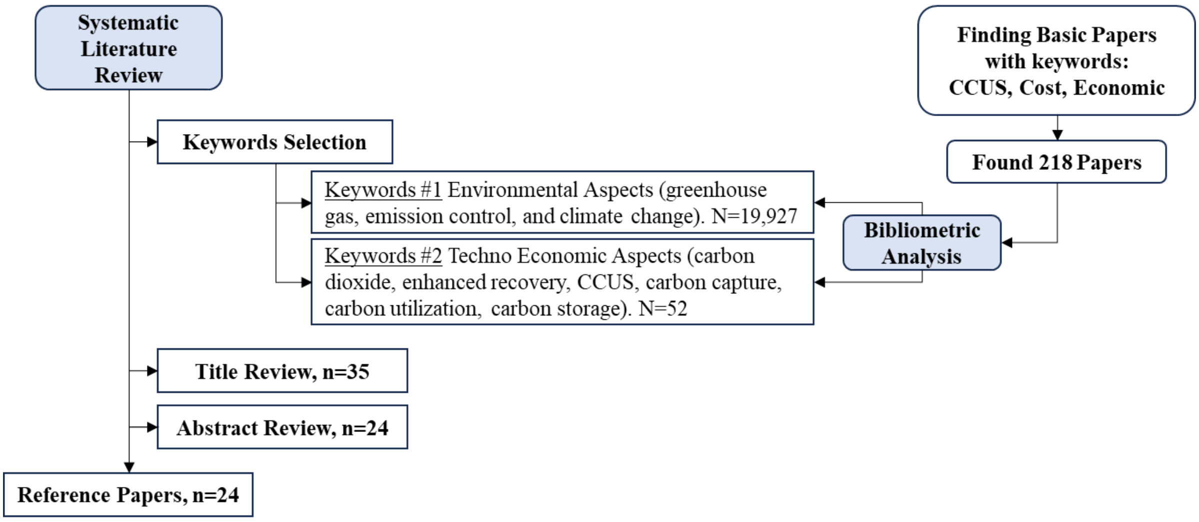

Figure 4. Literature selection process

The other 24 papers left over were used as the main reading materials and were considered as the key sources by the author. These papers, along with other relevant ones that were discovered during the research process, are referenced in this study. The Literature Review section provides a detailed overview of these papers. In order to identify the factors affecting the economics of CCUS projects in Indonesia and the driving forces that could facilitate CCUS implementation, researchers included 26 more relevant papers and documents to enrich the discussion, in addition to the 24 main articles that were used as primary sources and analyzed using VOS viewer.

3. Results

3.1 Climate Change

The global community began to take notice of climate change many years ago as people started to realize the significance of preserving the quality of the environment (Kaddo, 2016). In 1988, the IPCC was formed by the collaboration of the WMO and the UNEP.

The rise in global temperatures leading to climate change has numerous adverse effects, such as rising sea levels, submergence of small islands and coastal regions, high mortality rates among organisms, reduced agricultural output, shortages in food supply, proliferation of infectious diseases, and a shortage of clean water (Gunacti et al., 2023). The quick rise in global temperatures can be attributed to the actions of mankind (IPCC, 2021). The temperature has risen by 1.1oC in 2021 and experts estimate that within the next 1-5 years, the temperature could climb to 1.5oC higher than during the period of industrialization from 1850-1900. Today, around 75% of the emissions of gases that cause the greenhouse effect originate from the energy industry, wherein fossil fuels play a major role (IEA, 2021b).

Back in 1997, there was a global agreement called the Kyoto Protocol created with the aim of making cooperation on climate change more efficient. This agreement was later replaced by the Paris Agreement in 2015, which further improved international efforts to combat climate change (Ayuningsih et al., 2023). The Kyoto Protocol aimed to establish goals for advanced nations to decrease their emissions of greenhouse gases. Nevertheless, it was later discovered that the Kyoto Protocol did not make a substantial impact in the efforts to lower GHG emissions (Lukose, 2017). Despite the ratification of the Kyoto Protocol by many countries, emissions are still increasing (Kim et al., 2020). The Paris Agreement was established during the COP-21 conference in Paris in 2015 (United Nations, 2015). The Paris Agreement was established with the understanding that all members have shared responsibilities, but with consideration for each individual's unique capabilities. The objective is to improve initiatives aimed at decreasing emissions and addressing global climate change (Hein et al., 2018). The foundation of new worldwide cooperation and actions to reduce emissions and prevent the global temperature from rising above 1.5°C by 2030 is established by the Paris Agreement.

Indonesia is among the countries that have agreed to the terms of the Paris Agreement and continues to work diligently to address climate change. The first NDC was established in 2016, precisely one year after the Paris Agreement, to commemorate this pledge. According to the first NDC, Indonesia aimed to reduce emissions by 29% by national efforts or 41% with international support. The energy sector was expected to do so by 314 or 398 MTon CO_2e. Five years later, in July 2021, Indonesia released its most recent NDC with a more aggressive goal, with international support, the energy sector emission reduction target was raised to 446 MTon CO_2e, or a 12.06% increase. The more ambitious objective stated in Indonesia's Enhanced NDC report, unveiled a year afterwards, is to decrease emissions by 31.89% through domestic initiatives or 43.20% with assistance from the international community. With national efforts, energy sector emissions rose to 358 MTon CO_2e.

3.2 Emission Control and CCUS

CCUS has become more important recently, highlighted in the European Green Deal of 2019 and acknowledged by the IEA (IEA, 2021b). Critics claim that the cost of the technology is higher than that of wind and solar power (IEA, 2021a).

The objective of keeping the temperature increase below 2 degrees Celsius, as outlined in the 21st United Nations Climate Change Conference (COP-21), requires a reduction in carbon emissions by 40% by 2030 and 80% by 2050, relative to 1990 levels. GHG emissions, particularly CO_2, CH_4, and N_2O, are the primary culprits behind climate change (Kumar et al., 2020). Carbon dioxide is the most crucial gas in the greenhouse effect due to its widespread presence in the atmosphere, rapid release, and extended stay compared to other gases (Kumar & Imam, 2013).

CCUS is considered an effective approach to reducing emissions and achieving decarbonization objectives (Talebian et al., 2023). Based on Li et al. (2022), 63% of greenhouse emissions that contributed to the warming of the planet were due to CO_2. CCUS has aided in the effort to decrease CO_2 emissions by 15% and is expected to grow even more as technology progresses. This information emphasizes the importance of government and stakeholders focusing on CCUS (and/or CCS) initiatives that must be utilized; neglecting them could cause the cost of reducing emissions to rise by 138% (Leonzio et al., 2019; Leonzio et al., 2020b).

Studies carried out by Chaturvedi & Sharma (2023) infered that different techniques of injecting CO_2 in CCUS operations for boosting crude oil output have been proven to have a molar replacement efficiency of 0.5 to 1.5, demonstrating their ability to decrease CO_2 emissions. Therefore, CCUS is a key player in mitigating and regulating CO_2-induced emissions.

It was discovered by Robertson & Mousavian (2022) that most of the CO_2 that is utilized is primarily for the intendent of boosting the production of oil and gas through CO_2-EOR, with industrial applications being minimal in comparison (Figure 5).

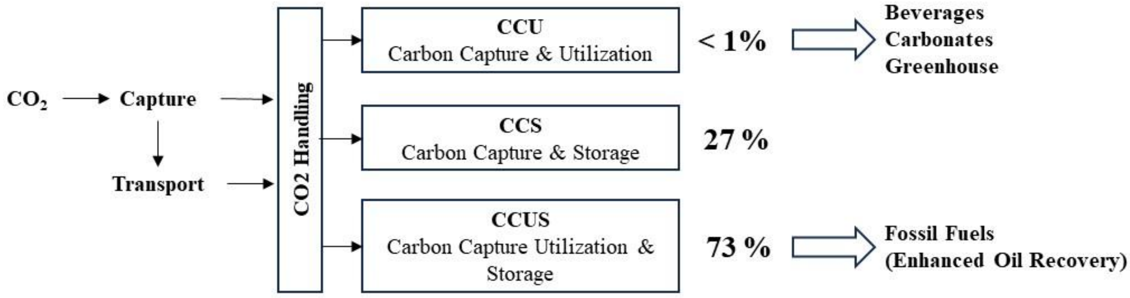

Figure 5. CO_2 handling distribution (Robertson & Mousavian, 2022)

The quantity of carbon dioxide that is pumped and stored in the CCUS project for CO_2-EOR usually surpasses the overall carbon dioxide emissions produced while extracting oil, transporting fuel, and refining it (Godec et al., 2017). CO^2-EOR is typically successful in depleted reservoirs with low water percentages, as well as in reservoirs where production has not been boosted through water injection methods (Vishal et al., 2021). By mid-September 2021, at least 130 facilities related to CCUS have started building, with a few already up and running (Talebian et al., 2023). CCUS has been primarily utilized in the United States for effective storage of large amounts of CO_2 (Nath et al., 2024).

In response to the climate crisis and the need to decarbonize the energy sector, CCUS technology is now seen as a strategic solution that can bridge the gap between environmental sustainability and energy security, particularly in developing countries. Various studies and initiatives have been undertaken to test the technical, economic and policy feasibility of CCUS implementation, both at the national and global levels. In the context of Southeast Asia, Thailand and Indonesia stand out as two countries that are beginning to actively explore and develop CCUS projects, including integration with EOR that enables the utilization of CO_2 to increase oil production while reducing emissions. The following analysis presents a comparison of various studies related to CCUS implementation, covering project location, types of technology used, actors involved, and relevant challenges and policy recommendations, as summarized in Table 3.

Thailand has implemented a real-world project through the Thailand CCUS Hub that targets CO_2 storage of 6 Mtpa by 2030 and increasing to 40 Mtpa by 2050, with great potential in the Eastern Seaboard (Sutabutr, 2024). The project is supported by collaboration between oil and gas companies such as PTT and PTTEP and the energy ministry, which emphasizes the need to accelerate CO_2 regulations, incentives, and infrastructure such as pipelines and offshore injection facilities.

Indonesia shows a more complex dynamic. According to a report (Ramadhan et al., 2024), there are more than 15 CCUS projects mostly in the oil and gas sector, with an ambitious target of 190 Mtpa CO_2 by 2060. The main emphasis is on the role of CCUS in the energy transition while maintaining national energy security. However, major challenges such as geological data variability and the need for cross-sector technical and policy integration still loom. Therefore, the expansion of regulations and fiscal incentives is a priority in encouraging the development of CCUS projects nationwide.

A more specific approach was demonstrated by Rakhiemah & Xu (2022) in their study of the CCUS-EOR project in East Java. The project showed positive financial results, generating a net profit of \$3.13/tCO_2 and 54 MMSTB of additional oil production over 15 years. The pure CO_2 source from the gas facility was also found to improve injection efficiency. Recommendations include adjustments to production sharing schemes such as PSC and Gross Split to support the sustainability of CCUS-EOR projects.

At the regional level, Bhaskara & Setyawati (2024) emphasized the importance of an ASEAN collaborative framework in CCS/CCUS development. ASEAN has more than 200 Gt of CO_2 storage capacity, with Indonesia and Malaysia being the most prepared countries. However, challenges such as limited geological data in countries like Laos and Myanmar, as well as a lack of legal coordination and regional funding, are major obstacles. Therefore, the establishment of an ASEAN CCS Value Chain Center (VCC), national legal frameworks and cross-border cooperation are urgent strategic recommendations.

Table 3. Research on CCUS project implementation in the Southeast Asia region

Study Location/ CCUS Project	Type of Technology Used	Key Findings	Policy Recommendation	References
Gulf of Thailand/ Rayong & Chonburi	1. Amine-based CO_2 capture, 2. Offshore injection, 3. CCUS Hub model	1. Thailand CCUS Hub targeted to store 6 Mtpa of CO_2 by 2030 and 40 Mtpa by 2050. 2. The geologic storage potential of the Eastern Seaboard is very large.	1. CCUS special regulation needed, 2. Accelerate the licensing process, subsidize the development of CO_2 transportation and storage infrastructure.	Sutabutr, 2024
Indonesia/National potential areas (aquifers, depleted fields)	Geological Focus: saline aquifers dan depleted oil/gas fields	1. There are more than 15 CCUS projects, mainly in the oil and gas sector. 2. Target 190 Mtpa by 2060. 3. CCUS supports the energy transition without compromising energy security.	1. Expansion of regulatory coverage across sectors (industry, power plants), 2. Establishment of a cross-border (ASEAN) project framework, and fiscal incentives.	Ramadhan et al., 2024
Indonesia/East Java - gas processing facilities and oil fields	1. Pure CO_2 from gas EOR; 5,546 tCO_2/day; 2. Oil field integration	1. The CCUS-EOR project in East Java generated a positive NPV, 2. Net profit of \$3.13/tCO_2, and an additional 54 MMSTB of oil over 15 years. 3. Pure CO_2 source improves efficiency	1. CCUS-EOR should be encouraged as a national pilot project. 2. Production sharing schemes such as PSC and Gross Split should be adjusted to support CCUS.	Rakhiemah & Xu, 2022
ASEAN region, especially Indonesia, Philippines, Malaysia, and Brunei	1. CCS & CCUS based geologic storage (saline aquifer, depleted fields) 2. EOR 3. Transport of CO_2 via pipeline/ship	1. ASEAN CCS Value Chain Centre (VCC) 2. ASEAN has >200 Gt CO2 storage capacity 3. Indonesia & Malaysia are most prepared	1. Need a regional legal and funding framework 2. Develop national CCS legal framework 3. Form a regional VCC 4. Increase funding and cross-border cooperation	Bhaskara & Setyawati, 2024

While approaches and levels of progress vary, all of these studies agree that successful implementation of CCUS requires strong regulatory support, economic incentives, collaboration across sectors and countries, and infrastructure and technology readiness. Another challenge is the need for long-term monitoring of storage sites. This monitoring is needed to detect CO_2 movement, potential migration, or indications of leakage that could harm local ecosystems. In the long term, consistent monitoring is an important instrument to ensure storage integrity and prevent unintended environmental consequences. From an economic perspective, the costs incurred to prevent leakage, mitigate its impacts and run the monitoring system are also a consideration in the financial viability of the CCUS project (Deng et al., 2017).

Potential environmental issues in CCUS initiatives are crucial aspects that must be considered to ensure successful and sustainable implementation. The main risk often cited is CO_2 leakage during transportation and underground storage, which can not only negate the environmental benefits of the technology, but also pose potential public health risks (Deng et al., 2017). In addition, geologic storage can induce seismicity, especially when conducted in areas with active faults. This risk requires in-depth geotechnical studies and continuous seismic monitoring (Mahjour & Faroughi, 2023; Xiao et al., 2024).

Long-term monitoring of storage sites poses another significant challenge necessarily. This monitoring is necessary to detect CO_2 movement, potential migration or indications of leakage that could harm local ecosystems. In the long term, consistent monitoring is an important tool to ensure storage integrity and prevent unintended environmental consequences. From an economic perspective, the costs incurred to prevent leakage, mitigate its impacts and run the monitoring system are also a consideration in the financial viability of the CCUS project (Deng et al., 2017).

To reduce these risks, several mitigation strategies need to be implemented, including a thorough geological characterization prior to storage, the use of advanced sealing technology, and the implementation of a multi-layered monitoring and surveillance system. A comprehensive risk assessment should also be an integral part of project planning, so that any potential hazards can be identified and anticipated early on. Thus, while CCUS has great potential to reduce carbon emissions, the success and safety of its implementation depend largely on how environmental risks are effectively and sustainably managed.

3.3 Cost of CCUS

Leonzio et al. (2020a) show the expenses involved in implementing CCUS in various European nations. Italy's annual expenditure for CCUS is EUR 77.3 billion, with an average cost of EUR 1,004 per ton of CO_2 captured. In Germany, the average cost per ton of CO_2 captured is EUR 613, leading to a total annual spending of EUR 98 billion. The UK stands out for its ability to lower the average cost to just EUR 164 per ton of CO_2 captured, resulting in a total annual expenditure of EUR 1.05 billion.

Hong (2022) reveals that the costs of CCUS are calculated by examining different activities and technologies used at each stage of the process.

a) The expense of capturing emissions varied between \$34 and \$74 per ton of CO_2 captured, with the exception of Direct Air Capture, which can cost as much as \$340 per ton of CO_2 captured.
b) The expense of capturing CO_2 using different separation methods varied from \$26 to \$90 per ton of CO_2 captured, with the exception of Biological-microalgae separation, which could cost as much as \$790 per ton of CO_2 captured.
c) The cost of transporting varies between \$1.72 and \$59.43 per ton of CO_2 captured, depending on whether ships, offshore pipelines, or onshore pipelines are used for delivery.
d) Utilizing CO_2 for EOR can potentially generate profits, but the expenses associated with storage and utilization may be as high as \$6.76 per ton of CO_2 stored. On the other hand, if the focus is solely on storage, the costs can vary between \$3.18 and 10.75 per ton of CO_2 stored.

Noticing a diverse array of expenses across different phases of CCUS operations indicates a lack of knowledge within the industry, both in terms of technical aspects and project management strategies. This presents an added difficulty in the adoption and implementation of this solution in Indonesia.

A cost analysis of CCUS in Indonesia reveals prospects for economic viability as well as a number of important challenges. One promising approach is the integration of CCUS with EOR, which enables the reduction of CO_2 emissions while increasing oil production. Key findings from research conducted by Rakhiemah & Xu (2022) show that the cost of implementing a CCUS project in Indonesia is estimated to be around USD 59 per tonne of CO_2 for the capture, storage and transportation process with a handling capacity of 5,546 tons of CO_2 per day. Further, Rakhiemah & Xu (2022) resulted in a positive NPV and net profit of USD 3.13 per ton of CO_2 at an oil price of USD 40 per barrel, indicating the potential profitability of CCUS-EOR projects on a local scale.

In terms of economic benefits, the CCUS-EOR project has the potential to generate additional oil recovery of 54 million stock tank barrels (MMSTB) over a 15-year operational period. Under both production sharing (PSC) and gross split schemes, the potential state revenue reaches between USD 211 million and USD 271 million, while the contractor's share ranges from USD 81 million to USD 141 million (Rakhiemah & Xu, 2022).

Furthermore, the research conducted by Raksawiguna et al. (2023) made an important contribution in evaluating the investment feasibility of CCUS projects in Indonesia through a quantitative economic approach, specifically using the Net Present Value (NPV) and Internal Rate of Return (IRR) methods. The study highlighted two integration scenarios, namely with an ammonia plant and with an oil field. The results of the analysis show that the CCUS project integrated with an ammonia plant has an NPV value of USD 661.95 million with an IRR of 13.54%, reflecting promising financial prospects. Meanwhile, the integration of the CCUS project with an oil field under the Gross Split Production Sharing Contract (PSC) scheme recorded an even higher IRR of 19.55%, indicating a more competitive return on investment. In addition, the study also included a sensitivity analysis of key economic variables such as oil price and capital expenditure, which showed that the viability of the project is strongly influenced by market and policy conditions. Therefore, government support in the form of conducive fiscal policies and investment incentives is crucial to increase the economic attractiveness of CCUS projects in Indonesia (Raksawiguna et al., 2023).

In terms of policy, the Government of Indonesia has shown its commitment through a plan to develop 15 CCUS projects by 2026, which is reinforced by regulations such as Permen of ESDM No. 2 of 2023 concerning Procedures for Implementing CCS Activities (Ramadhan et al., 2024). Collaboration between the government, industry players and academia is also crucial in overcoming the economic and environmental challenges that accompany the application of this technology (Ramadhan et al., 2024).

Still, challenges include high start-up costs, the need for specialized infrastructure, and environmental issues related to the safety of CO_2 storage. Thus, contrary to the assumption that there has been no use of quantitative economic models in the evaluation of CCUS in Indonesia, a number of recent studies have applied NPV and IRR approaches specific to the national context. While CCUS is a viable solution to support Indonesia's carbon emission reduction targets, these challenges remain major barriers to wide-scale implementation.

3.4 Economic Performance of CCUS

In 2020, a research study was conducted in Argentina, Gonzalo et al. (2020) researched CO_2-EOR, a type of CCUS technology in CCUS, demonstrated that CO_2-EOR offers notable benefits compared to Chemical-EOR due to its enhanced recovery rates and prompt response. The study utilized a financial model that took into account the economic conditions, policies, and cost evaluations by industry professionals in the country. The financial model's analysis of costs includes an oil price of 57 USD/bbl, a lifting cost of 27 USD/bbl divided into 70% fixed expenses and 30% variable expenses, and taxes of 15% that encompass royalties and national taxes. It was also noted that Argentine legislation could potentially cut royalties for EOR projects by half. Decreasing royalty fees could potentially impact the economy drastically and allow for higher amounts of CO_2 to be used at a greater cost for capture. At present, the region of Mendoza has presented the financial blueprint. This plan highlights the essential role of government assistance in implementing tax incentives and the expenses linked to CO_2.

An CCUS in Upper Silesia, Poland, includes analysis of present economic predictions and government regulations (Śliwińska et al., 2022). The situation acknowledges the local community's concerns and the current legislative efforts in Poland regarding CO_2 storage within the context of energy law. According to the CCUS scenario, there is a more favorable economic outlook with CCUS, estimating EUR 3807.19 million in comparison to a scenario without CO_2 capture and storage, which would face a CO_2 allowance price increase from EUR 46.30/tonCO_2 in 2021 to EUR 249.85/tonCO_2 in 2050. The findings indicate that the CCUS scenario remains financially viable even with a significant decrease in CO_2 emission allowance to as low as EUR 95.21/tonCO_2.

A study by Morgan et al. (2023) discovered that the NPV of the CCUS project was significantly impacted by fluctuations in oil prices and tax credits. To minimize total greenhouse gas emissions and maximize tax benefits and income from selling oil, a CO_2-EOR project focusing on CO_2 storage needs to thoroughly analyze various facets of the project's duration.

Carbon pricing through taxation or emissions trading schemes puts economic pressure on high-emitting industrial activities, encouraging the adoption of CCUS technologies as a cost mitigation strategy. Zhang et al. (2023) record that an effectively designed carbon pricing structure not only serves as a penalty for emissions, but also increases the economic value of the CO_2 captured and stored, thereby increasing the profitability of CCUS projects.

In addition, subsidies and tax incentives such as the 45Q scheme in the United States have been shown to play an important role in accelerating CCUS investment, particularly for the fossil fuel-based power generation sector. Although these technologies have relatively high costs compared to renewables, fiscal support can make CCUS projects commercially viable and attractive to investors (Grubert & Sawyer, 2023). Grubert & Sawyer (2023) also point out that financial incentives can encourage technological innovation and research, leading to improved efficiency and lower implementation costs in the long run.

Yet, the long-term effectiveness of this fiscal instrument is still debatable. Some critics warn that reliance on subsidies and tax credits can lead to misallocation of resources, as well as divert attention from climate solutions that may be more efficient and sustainable (Grubert & Sawyer, 2023).

3.5 Government Supports

Implementing CCUS technology is crucial in reducing CO_2 levels, however, the current pace of worldwide CCUS initiatives is insufficient to reach the goal of achieving zero net emissions by 2050 (Hong, 2022), and the expenses remain significantly elevated for implementing CCUS, making it challenging for private businesses to execute it on a large scale independently. Therefore, governmental involvement is necessary in order to introduce policies that promote the adoption of CCUS. In terms of offering incentives for CCUS initiatives, the United States is noted for its assertive approach among other nations.

Over the past twenty-five years, the United States has been heavily involved in the extensive development of CCUS, passing supportive laws, and pushing for technological advancements. The plan is divided into three distinct time frames. The initial stage, referred to as the Launch Phase, which spans over a period of 5-7 years, offered a financial incentive of $50 for each ton of CO_2, resulting in the creation of 10,000 jobs per year and achieving an annual capacity of 40 million tons. During the Growth Phase, which spans 15 years, the objective is to create 40,000 job opportunities each year and achieve an annual capacity of 150 million tons, with a monetary reward of USD 50 to 90 per ton of CO_2. In conclusion, the third stage, called the Expansion Phase (spanning 25 years), is projected to create 230,000 jobs each year and achieve a capacity of 50,000 tons of CO_2 with an estimated cost of USD 90 to 100 per ton in incentives (Li et al., 2022).

The CCUS program in China has evolved in two distinct phases: one prior to the announcement of the NZE-2050 target, and one after (Jiutian et al., 2022). The introduction of the CCUS initiative predates the NZE-2050 timeline, as it was initially recognized in the State Council's 2006 document outlining the country's long-term scientific and technological development. Subsequently, various related policies were released by government bodies such as the National Development and Reform Commission, the Ministry of Science and Technology, and the Ministry of Ecology and Environment. Moreover, several Chinese local authorities have implemented measures to promote the advancement of CCUS. Specifically, the Guangdong provincial government provides benefits for CCUS initiatives in the power generation sector.

China announced in 2020 its ambition to reach net-zero emissions by 2050, a target that has gained strong backing from the Chinese authorities. The introduction of the CCUS program in the 14th Five-Year Plan for Economic and Social Development in 2021 signaled a significant step forward. This move was quickly followed by the rollout of two comprehensive policies.

a) Guidelines for Achieving Carbon Dioxide Peak and Carbon Neutrality have been issued by the Chinese government to implement their New Development Philosophy. The policy, created by the Communist Party of China Central Committee and the State Council, aims to promote technological advancement.
b) Roadmap for Achieving Carbon Dioxide Peak by 2030 outlines a detailed strategy for the CCUS program, which includes advancements in technology, extensive testing, and collaboration on a global scale, released by the State Council.

In Shanxi province, China, a research was done using Mixed-Integer Linear Programming (MILP). The research suggests that the government should assist in enhancing process equipment and adopting new technology, offering clear guidance and policies, speeding up the construction of CCUS infrastructure, and aiding CCUS projects in high-carbon industries (Zhou et al., 2023).

A fresh method was implemented in Australia to assess the creation of blue hydrogen by utilizing Steam Methane Reforming (SMR) centers combined with CCUS within a spatial-technical economic model (Khan et al., 2021). The study outlines a method that utilizes CCUS to capture CO_2 during hydrogen (H_2) generation using SMR, resulting in the production of emission-free "blue H_2". The analysis considers four different scenarios in various regions of Australia, taking into account equipment costs, operational costs, and techno-economic factors such as carbon tax and labor costs. It emphasizes the importance of government intervention in determining production costs and prices. The expense of producing H_2 can differ depending on the location and operational configuration of SMR facilities. With higher natural gas and storage costs in Eastern Australia, and lower costs in Western Australia, the production costs of H_2 vary between regions. The paper also proposes utilizing CO_2 electrolysis to produce formic acid, highlighting the potential revenue generation and cost reduction of blue H_2 production by 4 to 9% with a medium-scale electrolyzer plant. Furthermore, increasing the capacity of the CO_2 electrolyzer and enhancing emission capture can reduce the reliance on CO_2 storage.

EOR-CO_2 activity has begun to be studied in India. They have started conducting seismic, geomechanical, and reservoir investigations. (Prajapati et al., 2024) emphasized the need for support from the Indian government to create a good environment for research and development, which can encourage CCUS innovation and investment.

In order to support the financial aspects of projects related to CCUS in Indonesia, the Indonesian government has taken steps such as issuing a presidential decree regarding the Economic Significance of Carbon (Presiden Republik Indonesia, 2021). In continuation of the aforementioned presidential decree, the Ministry of Environment and Forestry released a statement in 2022, subsequently, the Ministry of Energy and Mineral Resources issued the aforementioned.

The explanation mentioned showcases the various ways in which different countries approach policies, influenced by factors such as financial strength, environmental priorities, industrial development stage, and community awareness. As demonstrated by the percentage of the budget allocated to technology investment, research, and development of industrial process efficiency, as well as to increasing community capacity so that the environmental management process takes place comprehensively, not only in the industrial sector but also at the community level, it is understandable that a country's fiscal capacity has a positive correlation with its commitment to environmental management.

While Indonesia has shown commitment in developing CCUS technologies, wider adoption still faces significant legal and regulatory challenges. One of the main issues is the absence of comprehensive and specific regulations to govern the entire cycle of CCUS activities, including non-technical aspects such as financial incentives, international partnerships, and public participation. The Minister of Energy and Mineral Resources Regulation (Permen ESDM) No. 2 Year 2023 does provide an initial framework for CCS and CCUS activities in the oil and gas sector, but its scope is still limited to injection and storage activities, without clearly regulating licensing for entities that only conduct carbon capture without involvement in storage or injection. This creates a regulatory vacuum, which, according to BSD-Kadin.id, may hinder businesses that wish to focus solely on the carbon capture aspect of CCUS.

Yet, another challenge arises from the carbon pricing mechanism in Indonesia. Although Presidential Regulation No. 98 of 2021 has provided the legal basis for the implementation of carbon economics, the current carbon price is not high enough to effectively drive market demand for carbon credits. Uncertainty regarding the Corresponding Adjustment (CA) and Non-Corresponding Adjustment (NCA) mechanisms, which are still under development, is also an obstacle for investors, especially from abroad, who need legal and market certainty. Public awareness and understanding of the domestic industry sector regarding the economic value of carbon is still low, which adds to the challenge of implementing this policy effectively. Thus, despite initial policy progress, there is still a need for regulatory evaluation and refinement for Indonesia to create a legal and market ecosystem that supports the full and sustainable adoption of CCUS.

To align the economic policy of CCUS investment with global best practices, the Government of Indonesia needs to adopt a multidimensional approach that includes strengthening the regulatory framework, facilitating strategic partnerships, and optimizing the utilization of existing energy infrastructure. Regulatory reform is key in building legal certainty for industry players. Although there is already a legal basis, such as Presidential Regulation No. 14 of 2024 and Minister of Energy and Mineral Resources Regulation No. 2 of 2023, improvements are still needed on non-technical aspects such as the integration of licensing and contracting schemes, fiscal incentives, and transparency in carbon emission and storage reporting mechanisms. These improvements will enhance the credibility of national policies in supporting long-term investment in CCUS projects.

Beyond regulatory aspects, implementing global practices also requires collaboration between the public, private and academic sectors to strengthen the innovation ecosystem and mitigate technological risks. Case studies such as the Tangguh CO_2-EGR and Gundih CCS projects have shown how pilot projects can act as catalysts in expanding CCUS implementation nationwide (Ramadhan et al., 2024). In addition, utilizing existing oil and gas infrastructure is an efficient strategy to reduce initial implementation costs and accelerate the transition to a low-carbon energy system. CCUS technology integrated with EOR not only offers emission reduction potential, but also provides added economic value through increased oil production (Handaja et al., 2024).

Economically, recent studies indicate that high-purity natural gas CO_2 processing facilities are the most cost-effective option for the initial phase of CCUS implementation in Indonesia (Ramadhan et al., 2024). However, significant challenges remain, particularly related to infrastructure costs, uncertainties in carbon market mechanisms, and limited long-term technology performance data. Therefore, strengthening the fiscal framework in the form of competitive carbon pricing schemes, tax incentives, and blended financing mechanisms to attract private sector and international investment is required. In the future, the integration of CCUS with renewable energy sources and the mainstreaming of socio-environmental aspects in project evaluation are important strategies to ensure Indonesia's sustainability and competitiveness at the global level.

3.6 Collaborative Effort

CCUS, a newer method for decreasing emissions, is encountering economic obstacles in becoming an appealing investment opportunity. Collaboration has been practiced since the time of the Kyoto Protocol through carbon trading, allowing investors in emission reduction to potentially earn back a portion of their invested funds by trading leftover emission quotas. Due to its high cost of capital, CCUS requires collaborative efforts and advancements in carbon trading to enhance its economic viability (Hong, 2022). In the same way, CCUS projects require a business-driven approach and active involvement from the industry, drawing inspiration from the U.S. Department of Energy’s CarbonSAFE Initiative (Turan, 2024). Businesses may mitigate project risks, uncertainties, and expenses through cooperative ventures.

Many companies in Europe, the USA, and Asia Pacific have come together to collaborate on various projects. The Global Status of CCS 2021 Report: Companies have come together to collaborate on the CCS project, focusing on transportation and storage infrastructure like pipelines, shipping, ports, and geological layer storage.

Collaboration has been challenging at times, as seen in the struggles faced by the Petra Nova project of CarbonSAFE Initiatives in the U.S. The project highlights the difficulties of aligning the interests of different businesses in order to advance CCUS and reach agreements among stakeholders to move the project forward (Sullivan et al., 2020). Many nations and businesses have joined forces to try and minimize the expenses associated with CCUS through collective action. A key component of the CCUS implementation process is collaboration, which encompasses both technological and financial elements. The NDC document states that international support is required for emission reduction pledges, and given Indonesia's current situation, it is still very difficult to dedicate a greater budget for the implementation of CCUS. As a result, an international support mechanism is required.

Public and community acceptance of CCUS projects is a crucial aspect that determines the successful implementation of this technology, but has not been discussed in depth in this study. The level of public acceptance directly affects policy adoption by the government and the perception of investment risk by market participants. Public non-acceptance can lead to project rejection, delay, and even cancellation, which is not only economically costly but also hampers the achievement of climate change mitigation targets. Some of the key factors that influence public acceptance include the level of trust in the technology and implementing agencies, perceptions of risks and benefits, and the quality of communication and transparency of information conveyed to the community. This lack of engagement can increase project uncertainty in the eyes of investors, thereby increasing investment risk and decreasing funding interest. Therefore, strategies such as the provision of clear information, active and transparent community engagement, and an emphasis on local benefits such as job creation or improved environmental quality, are critical to increasing public acceptance and supporting the long-term success of CCUS projects. Without strong public support, the implementation of CCUS technologies could potentially face significant social barriers, even if they are considered technically and economically feasible.

3.7 Implementation of Paris Agreement Commitment

In the continuation of enforcing the approval of the Paris Agreement (UU 16/2016 Tentang Pengesahan Paris

Agreement To The UNFCCC (Persetujuan Paris Atas Konvensi Kerangka Kerja Perserikatan Bangsa-Bangsa Mengenai Perubahan Iklim)), in 2018, the Indonesian government demonstrated its dedication by releasing a document known as the NDC. These NDC documents and regular reports from the Indonesian government are valuable resources for securing funding through the Paris Agreement process. The Indonesian government's 2nd Biennial Update Report under the UNFCCC also provides important information reported that achieving the CM-1 target of the NDC will necessitate a total of $247 billion in funding by 2030. The funds required for CM-2 are estimated to be approximately $285 billion by 2030, as indicated in Indonesia's 3rd Biennial Update Report submitted to the UNFCCC. The Indonesian government made enhancements to their NDC commitment in 2021, which was then updated to an Enhanced NDC in 2022.

To secure funding for initiatives aimed at reducing emissions, the Paris Agreement (United Nations, 2015) Article 9 mandates that developed nations provide financial assistance to developing nations. By the year 2050, wealthy countries have committed to giving $100 billion each year to support developing countries in addressing issues related to climate change. Nevertheless, this amount falls short of the requirements outlined by the IPCC, which suggests that between $1.6 and $3.8 trillion per year is necessary until 2050 to combat global warming. If prosperous countries that are members of the Paris Accord uphold their obligations to offer financial support for Indonesia's NDC, a portion of the funds could be allocated towards supporting the execution of the CCUS initiative in Indonesia.

The role of renewable energy and alternative decarbonization strategies has not received sufficient attention in Indonesia's decarbonization policy framework. While carbon pricing has been a key instrument in reducing emissions, this approach is still general and does not fully consider the need for sector-specific strategies and the urgency of energy efficiency as a driver of the low-carbon transition. Decarbonization efforts often focus on the electricity generation sector, ignoring structural challenges in hard-to-decarbonize sectors such as transportation, heavy industry and agriculture, which require innovative technologies such as direct electrification, green hydrogen and sustainable bioenergy (Papadis & Tsatsaronis, 2020; Tian et al., 2023).

In addition, one-size-fits-all policies have proven inadequate to deal with the different structural and institutional challenges in each sector. Therefore, a more contextualized and locally-based approach is needed to identify sources of technological lock-in and unlock opportunities for innovation. The role of energy efficiency is also crucial in reducing overall energy demand, which in turn accelerates the transition to a low-carbon energy system in a more cost-effective manner (Kim et al., 2024).

The challenges of energy transition involve interrelated social, economic, environmental, technical and institutional dimensions. This demands a holistic approach and renewable energy policy formulation that is evidence-based and adaptive to local dynamics. The lack of consistency in climate policy is also an obstacle in encouraging investment in the clean energy sector, as it creates uncertainty for investors. Therefore, policy stability and targeted incentives are needed to encourage a shift in investment from carbon-based technologies to low-emission solutions (Papadis & Tsatsaronis, 2020). The lack of a transparent and credible legal and regulatory framework in developing countries can further complicate the implementation of PPAs (Chrysikopoulos et al., 2024). Decarbonization efforts, if not designed with equity in mind, risk exacerbating existing social inequalities, as vulnerable groups may not have access to clean technologies or face greater economic burdens from the transition (Mohamed et al., 2025). In summary, the impact of the energy transition on the energy market is multifaceted, including positive impacts on environmental protection, energy security, economic development and social equality (Zhou, 2023). Renewable energy development in OECD countries is complexly influenced by various factors, where overly aggressive decarbonization policies can actually hinder the development of renewable energy (Hao & Khan, 2025). In contrast, a strategic and gradual energy transition, optimized natural resource management, and reduced dependence on fossil energy have been shown to promote clean energy growth (Hao & Khan, 2025). Therefore, a balanced and comprehensive policy approach is required to ensure the success of a sustainable energy transition.

Apart from the obligation to mobilize funds, the Paris Agreement also encourages parties to innovate and implement technology that supports emissions reduction efforts. Furthermore, developed nations should also increase assistance for training programs in developing countries. Funding support for research and development, funding support for technology installation, and, of course, educational scholarships on subjects that are pertinent to communities in developing nations are all ways to create capacity.

Alternative financing mechanisms play a strategic role in supporting the development and implementation of CCUS technologies as part of energy and industrial sector decarbonization efforts. As global commitments to net-zero emission targets increase, private sector financing, carbon credit markets, green bonds, and climate finance initiatives are key pillars that can accelerate the deployment of these technologies. Private sector investment, driven by fiscal incentives such as tax credits and subsidies, is proven to stimulate technology development and scale-up of CCUS projects (Pratama & Mac Dowell, 2022; Purkayastha & Sarkar, 2021). On the other hand, the carbon credit market acts as an economic instrument that enables the monetization of emission reduction benefits, thereby improving the financial viability of projects. Green bonds are also an important means of raising capital in line with sustainability principles, as well as strengthening the company's image in the eyes of environmentally conscious investors. Equally important, climate finance initiatives such as blended finance can lower the risk and cost of capital through the collaboration of public and private funds, and the provision of risk guarantees (Purkayastha & Sarkar, 2021). However, there are still challenges to overcome, such as regulatory harmonization, low carbon prices, and the complexity of green project eligibility criteria. Therefore, a more progressive policy framework and innovations in financing models are needed to ensure CCUS technologies can contribute significantly to the transition to a low-carbon economy.

3.8 Summary

This part combines the information from the preceding section, highlighting the interconnected elements that must be effectively combined to address the obstacles facing the CCUS program.

The whole sequence of CCUS operations comes with a significant price tag ranging from $60 to upwards of $1,000 per ton of CO_2. The procedures include (1) collecting CO_2 discharges from multiple origins. (2) Dividing the CO2 elements apart. (3) Conveying the separated CO_2. (4) Applying it in various sectors, like enhancing oil and gas development. (5) Depositing it in underground rock structures. These five comprehensive high-cost operations require financial support from the government, especially for the integration of CCUS in Indonesia. Apart from the United States, where there are regulations in place to provide substantial incentives for investing in CCUS technology, the economic benefits of carbon generated through different commercial avenues yield lower profits. The situation in the US highlights the necessity of government policies to encourage the enhancement of the financial aspects of investing in CCUS technology.

Collaboration among various companies and countries through hub facilities can enhance the economic aspects of CCUS. These hubs can be set up as CO_2 collection stations located in the middle of the process, allowing for the transport of CO_2 via pipelines, trucks, or ships to other locations for various purposes. With the establishment of hubs, the costs of investment and operations can be divided among multiple parties, resulting in shared benefits and increased efficiency.

A method to assist the financial dimensions of CCUS initiatives in Indonesia is by leveraging the protocol established in Article 9 of the Paris Agreement. As per the agreement, each nation is required to contribute to emission reduction efforts according to their individual capacities and resources as defined in their NDC filings. Developed countries are anticipated to provide financial assistance and help in technological improvements, while also aiding in the enhancement of skills and resources for less developed countries that face a significant threat from the effects of climate change. Funding support mechanisms for technology installation, research and development funding, and scholarships for specialized on postdoctoral and dissertation themes pertinent to CCUS are all ways to enhance capacity for developing countries.

This study has some limitations that need to be recognized. First, this study has not been supported by primary data, such as direct case studies of CCUS projects that are underway or have been underway in Indonesia. Therefore, the analysis presented relies more on global literature and findings from other countries, which may have different regulatory, economic and technological contexts from Indonesia. Secondly, the bibliometric approach used in this study has the potential to contain representational bias, particularly due to the dominance of publications from the European and North American regions. This could lead to an imbalance in knowledge mapping and research trends, and reduce the visibility of scientific contributions from developing countries such as Indonesia. In the future, there is a need to collect contextual data from domestic CCUS projects and a more inclusive analytical approach to literature from the Southeast Asian region, so that the research results can reflect a more accurate and locally relevant reality.

4. Conclusions

There are three crucial factors that determine the success of CCUS project implementation in Indonesia, namely government policy and commitment, cross-sector collaboration, and support through financing schemes from the Paris Agreement. These three are the main pillars in driving the economic and technical feasibility of CCUS as part of the national decarbonization strategy. The Indonesian government has demonstrated its commitment to climate change mitigation through the ratification of the Paris Agreement (Law 16/2016), the preparation of the NDC document, and the update to the Enhanced NDC in 2022. However, to achieve the CM-1 and CM-2 targets in the NDC, Indonesia requires funding of USD 247 billion and USD 285 billion, respectively, until 2030. Therefore, Indonesia needs to optimize financing opportunities from developed countries as mandated in Article 9 of the Paris Agreement.

In the future, concrete steps that can be taken include the development of pilot CCUS projects in the energy and industrial sectors as evidence of feasibility at the national level. Building public-private partnerships to attract investments, as well as formulating fiscal policies and incentives such as carbon credits and low-carbon technology subsidies, will also be essential. Additionally, integrating CCUS targets into the national energy roadmap and energy transition roadmap is crucial to ensure synchronization with NDC and Net Zero Emissions 2060 targets.

With conducive policies, close collaboration, and targeted international support, CCUS can become a strategic solution in reducing emissions and promoting sustainable development in Indonesia.

In connection with the preceding information, the author identified three crucial factors for the achievement of CCUS implementation: advocating for governmental backing in creating a policy framework to bolster and incentivize investment in CCUS; promoting cooperation among polluters to divide expenses; and stressing the enforcement of Article 9 of the Paris Agreement, which mandates developed nations to mobilize funds, aid in building capacities, and offer technology assistance.

The author found a lack of integrated action involving those three key elements. This research has not found adequate worldwide data demonstrating the implementation of the integrated action, especially in Indonesia where CCUS is relatively new. The Government of Indonesia needs to facilitate discussion and gather feedback from stakeholders, allowing implementation of the said integrated action.

In order to successfully implement CCUS on a large scale, it is crucial to develop a strong strategy and plan. The author suggests conducting additional research and studies to assess the effectiveness of different policy approaches around the world. Factors such as cultural differences, social dynamics, and geographical considerations should be taken into account when evaluating the outcomes of these policies. Exploring creative business models is essential for enhancing the effectiveness of investments in CCUS.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest

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