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Exploring Public Attitudes and Acceptance of CCUS Technologies in JABODETABEK: A Cross-Sectional Study

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Abstract: One of the most essential elements of environmental protection is an appropriate policy towards carbon capture, utilisation, and storage (CCUS). On the one hand, these technologies are being dynamically developed. Still, on the other hand, we often encounter social resistance to change and new technologies, which is one of the main barriers to their implementation. This research examined public acceptance and awareness of Indonesia's CCUS technologies. Five hundred respondents completed an online survey representing Jakarta, Bogor, Depok, Bekasi, and Tangerang. The study found that the respondents had more favourable feelings towards carbon capture and utilisation (CCU) than CO_2 capture and storage (CCS), perceiving CCU as more innovative, necessary, cost-effective, secure, environmentally friendly, and beneficial to regional and national economies than CCS. However, in Indonesia, most respondents did not embrace the development of CCUS technology due to a lack of knowledge and fear, which can lead to violence. The results indicate that an individual's awareness of perceived risks and the ability to safeguard the environment are crucial to their acceptance of CCUS technology. These findings contribute to understanding the public perception of CCUS technologies in Indonesia and can help to develop effective communication strategies to improve public understanding and acceptance of CCUS initiatives.

Keywords: CO_2; CCU; CCS; carbon capture; carbon utilisation; carbon storage; public acceptance; cross-sectional study

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1. Introduction

The issue of the public understanding and acceptance of carbon capture, storage, and utilisation (CCUS) technologies has attracted the attention of governments, actors in the energy industry, and academics. It is widely acknowledged that stakeholders and the general public can substantially influence investment and location decisions for CO_2 capture, storage, and utilisation facilities, as well as CO_2-derived products [1]. As a result, understanding the attitudes and perceptions of the public towards CCUS technologies is crucial to the design and implementation of effective strategies for public participation in potential CCUS initiatives in Europe [2]. Given the increasing urgency of addressing climate change by reducing carbon emissions and the potential role of CCUS technologies in achieving this goal, this is particularly relevant.

During the last two decades, social researchers have paid considerable attention to investigating public attitudes towards CCUS technologies [3,4]. This body of work has included studies exploring the degree of public awareness and understanding of CCS projects and the factors that contribute to the support or opposition of CCUS technologies in various contexts and populations. In reviewing the available studies, the general trend suggests moderate public acceptance of CCUS technologies [5]. These findings have important implications for policymakers, industry stakeholders, and researchers, as they suggest that efforts to promote the widespread implementation of CCUS technologies may be met with varying levels of public support and opposition [6]. More research is needed to explore the factors that underpin these attitudes and identify effective strategies for engaging the public in conversations around CCUS technologies.

Several studies [1,3,4] have examined the public's perceptions of CCU and CCS and found that CCU is generally viewed more favourably than CCS. Furthermore, among the numerous aspects of CCUS technologies, CO_2 storage receives the lowest level of public acceptance [7]. However, it is important to note that the configuration of the application case can influence public attitudes towards these technologies. For example, a study by Loukouzas et al. [8] found that the general public preferred scenarios combining CCS with bioenergy over those that involve shale gas, underground coal gasification, or heavy industry. Similarly, a second study [9] found that the general public preferred CCS in conjunction with bioenergy and heavy industry over coal-fired power plants. When examining public perceptions and attitudes towards CCUS technologies, it is crucial to consider the contexts in which they are implemented [10].

In addition to examining the general public's attitudes towards CCUS technologies, several studies have investigated whether individuals who are likely to be directly affected by adjacent CCS installations have different perceptions of the technology than the general public. The results of these investigations have been contradictory. Some studies [11,12] have found that CCS scepticism is higher in areas where CCS storage may impact residents. However, a more recent study involving five countries (Canada, the Netherlands, Norway, the United States, and the United Kingdom) by [13] found that local samples exhibited the same or even higher levels of acceptance for CCS than the general population. These discrepancies in the findings illustrate the difficulty in understanding public perceptions of CCUS technologies and suggest that the local context and other factors may play a role in determining attitudes towards these technologies.

The public acceptance of CCUS technology is influenced by its perceived risks and advantages [10,14]. CO_2 leaks or blowouts, induced seismicity, and local repercussions on property values or tourism are only some of the potential concerns [15]. There is also some doubt as to whether or not CCS is a long-term solution to keep polluting companies around. On the contrary, CCS is primarily lauded for its potential to aid in the fight against global warming. CCS is also believed to provide local economic advantages and ease the transition to a decarbonised society [8,9,14].

The level of trust people have significantly influences public opinion on CCUS technologies among relevant stakeholders [16,17]. Public confidence can be increased through effective communication with stakeholders, especially when the message is seen to align with the interests of those involved [15]. Although the links between these components have not been demonstrated, some researchers have also investigated how affect and prior attitudes play a role in determining public perceptions of CCUS technology [11,14,18]. These results highlight the importance of thinking about the various elements that affect the way people see CCUS technologies. Effective public engagement initiatives might benefit from policymakers and industry stakeholders talking to the public and learning about their concerns and goals [19].

The CCUS Project has been trying to figure out why the reception of CCUS projects varies. This research aims to contribute to this cause by investigating the general public's familiarity with and attitude towards CCUS technology in Indonesia. Except for a few notable exceptions [20,21], the social acceptance of CCUS technology has received less attention in these countries in recent years [22,23].

Based on the above review [1–23], three questions can be formulated, the answers to which will help fill the identified research gap:

- To what extent does the public know, understand, value, and accept CCS and CCU technologies?

- How does the public perceive and respond to CCS and CCU technologies?
- What are the determinants of people's willingness to adopt CCS and CCU technologies?

The successful deployment of CCUS technologies requires first gaining a thorough understanding of how the public views these innovations. The public's understanding, perception of benefits and costs, and general evaluation and acceptability can help policymakers and industry stakeholders build more effective public participation programmes. Reporting on social acceptance sheds light on how acceptance differs between different research populations, but identifying important individual determinants of acceptance can also help to target specific communities and resolve their concerns.

The understanding and acceptance of carbon capture, storage, and utilisation (CCUS) technologies by the general public have been a major concern for governments, industry actors, and academics. It is widely acknowledged that stakeholders and the general public can have a significant impact on investment and location decisions for CO_2 capture, storage, and utilisation facilities, as well as CO_2-derived products. Therefore, it is essential to understand public attitudes and perceptions towards CCUS technologies to develop and implement effective public engagement strategies in Indonesia for potential CCUS initiatives. Given the increasing urgency of addressing climate change by reducing carbon emissions and the potential role of CCUS technologies in achieving this goal, this is particularly relevant.

Social scientists have devoted substantial amounts of attention to analysing public attitudes towards CCUS technologies. This research included studies examining the level of public awareness and understanding of CCS initiatives, as well as the factors that contribute to the support or opposition of CCUS technologies in diverse contexts and populations. The available studies suggest that public adoption of CCUS technologies is generally moderate. These findings have significant implications for policymakers, industry stakeholders, and researchers, as they suggest that efforts to promote the widespread adoption of CCUS technologies may be met with variable degrees of public support and opposition. Therefore, additional research is required to investigate the factors underlying these attitudes and to identify effective strategies to involve the public in discussions about CCUS technologies.

1.1. CCS and CCU for Indonesia

Indonesia is a developing nation with abundant fossil fuel resources, and fossil fuels will continue to be the primary energy source for decades to come. In an effort to mitigate climate change, the Indonesian government has committed to reducing greenhouse gas emissions from fossil fuel consumption. Figure 1 shows the poor air quality in Indonesia as a result of greenhouse gas emissions.

Indonesia has initiated research related to CCUS as a means to address the issue of climate change and reduce CO_2 emissions. However, it should be noted that this particular programme addresses the function of natural carbon dioxide sequestration, as opposed to carbon dioxide conversion. The concept of carbon capture and utilisation (CCU) technology involves the transformation of carbon dioxide (CO_2) into a range of valuable products. Usman investigated the synthesis of various chemical compounds, such as carboxylates, carbonates, carbamates, isocyanates, and polymeric materials, from CO_2 [22] for their potential applications in electrochemistry and photochemistry. According to Jiutian et al. [23], the activation of CO_2 and its co-reactants can produce valuable chemicals using high-energy salts or catalysts.

The utilisation of fossil fuels has demonstrated a notable increase, rising from 53.4 million tonnes of oil equivalent (Mtoe) in 1990 to 154.93 Mtoe in 2013. During this period, the proportion of oil consumption ranged from 50% to 60%. Under the NEP scenario, the proportion of oil in the energy mix is projected to decrease to 25–30%, while the aggregate consumption of fossil fuels is expected to rise to 690 Mtoe by 2050. The escalation in the use of fossil fuels is expected to be accompanied by a corresponding increase in carbon dioxide emissions [18]. The number of CO_2 emissions in 1990 was recorded at 133.9 Mtoe, which remained constant at 133.9 Mtoe in 2013. According to projections, global energy consumption is expected to reach 1000.6 and 2065.98 Mtoe in 2030 and 2050, respectively. According to LEMIGAS [18], the Indonesian government projected that the depleted oil and gas fields located in Kutai, Tarakan, and the South Sumatra region have the potential to store approximately 640 Mtoe of CO_2.

Figure 1. Effect of greenhouse gas emissions in JABODETABEK. Source: https://www.thejakartapost.com, accessed on 2 May 2023.

According to Rakhiemah [24], the most appealing alternative for CCS in Indonesia is the combination of CO_2 storage with EOR. This is due to the possibility of generating additional revenue from oil production, which can counterbalance the expenses associated with CCS. However, it is anticipated that this alternative will not meet the CO_2 reduction objective for extended-term CCS, as the utilisation of oil generated from EOR results in CO_2 emissions. Moreover, implementing carbon capture and storage (CCS) in the power industry can alleviate carbon dioxide emissions and accelerate industrialisation by facilitating the construction of additional power plants to meet the country's electrification objectives.

1.2. Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) Technologies

Carbon capture and storage (CCS) entails extracting carbon dioxide from industrial emissions and then storing it permanently in geological formations. The technique is commonly used in various industries, such as cement, steel, power generation, and chemical production. In contrast, carbon capture and utilisation (CCU) is part of a broader set of carbon recycling applications describing the reuse of captured carbon either directly (e.g., to fertilise greenhouses in beverages) or as an ingredient in new products (e.g., concrete, fuel, and chemicals). CCUs can replace the use of additional fossil fuels, thereby reducing emissions. This method can be considered a removal if carbon is removed from the atmosphere and remains in a closed circle for decades or centuries (e.g., when incorporated into cement building materials).

CCS technology is utilised to regulate the emission of CO_2 trapped from various processes, such as precombustion, post-combustion, and oxy-fuel combustion. The stages of a CCS project can be categorised into four phases: CO_2 capture, CO_2 transportation, CO_2 injection, and post-injection of CO_2 [25,26].

In the short term, storing CO_2 in geological locations such as deep saline formations, depleted oil or gas reservoirs, deep unmineable coal seams, and shale formations can reduce CO_2 emissions [27], as shown in Figure 2. Compared to pure CCS technology, CCUS technology focusses more on using captured CO_2, while sequestration (S) is secondary.

CCUS technology can reduce the cost of sequestration and provide benefits by enhancing the production of hydrocarbons or heat energy. Therefore, it has gained popularity in recent years. Depending on the purpose of CO_2 injection, several related technologies have been developed, including Enhanced Oil Recovery (EOR), Enhanced Coalbed Methane Recovery (ECBM), Enhanced Gas Recovery (EGR), Enhanced Shale Gas Recovery (ESG), and Enhanced Geothermal Systems (EGSs).

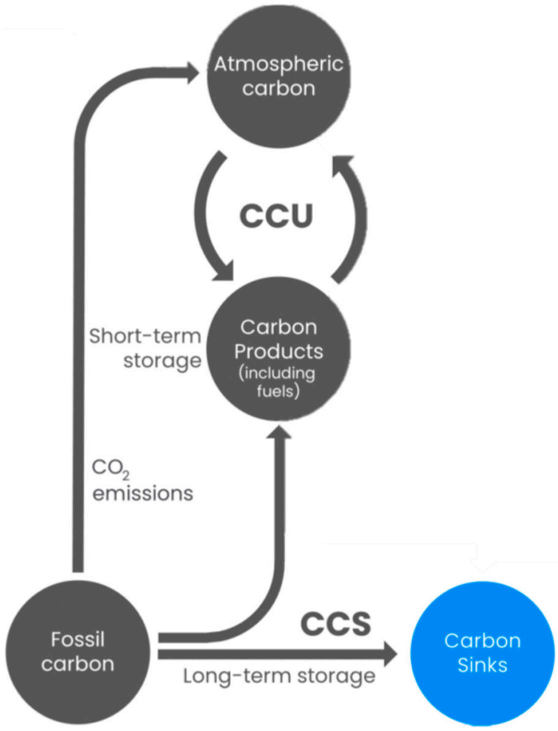

Figure 2. CCS and CCU process. Source: own elaboration.

The engineering projects for CCS and CCUS technologies are highly complex and require extensive research in various engineering and science disciplines, including geology, geoengineering, geophysics, environmental engineering, mathematics, and computer science, for their successful implementation. The site selection process for these projects is crucial to their success and must consider safety, the economy, the environment, and public acceptance at all levels of operation, including country-wide, basin-wide, regional, or sub-basin levels [28,29]. Although CCS and CCUS technologies have similarities in their site selection process, they will induce different physical and chemical responses in underground porous or fractured rock formations, depending on existing hydrological (H), thermal (T), mechanical (M), and chemical (C) fields [30,31].

In the following sections, we examine the key study variables in each population: knowledge, attitudes, perceptions, preferences, acceptance, and trust. CCUS technologies will be the focus of our attention. We will also compare and contrast these factors based on age, sex, and socioeconomic status. The variables that influence the spread of CCU and CCS systems will be the subject of future research. In the last section, we discuss and conclude this study by pointing out the theoretical and practical implications of the research conducted.

2. Materials and Methods

2.1. Participants

The JABODETABEK region was selected as the focus of this study due to its unique geographical location and high levels of tourism, resulting in increased CO_2 emissions. The region is also a hub for economic and social development, with a rapidly growing population and an increasing demand for energy. Therefore, understanding public attitudes towards CCUS technologies in this region is critical for developing effective climate change mitigation strategies.

The region is located on the northwest coast of Java Island and includes the cities of Jakarta, Bogor, Depok, Bekasi, and Tangerang. It is a popular tourist destination and attracts millions of visitors annually, making it one of the largest contributors to greenhouse gas emissions in the region. Furthermore, the JABODETABEK region is experiencing rapid economic and social growth, making it an excellent benchmark for evaluating the social acceptance of CCUS technologies.

A total of 500 people were included in this study, with 100 people from each of the five cities. The people of Jakarta, Bogor, Depok, Bekasi, and Tangerang were the pool from which the participants were drawn. The research team used an online form to find all participants at least 18 years of age.

2.2. Procedure

The research team devised a web-based survey to examine public sentiments about carbon capture and utilisation systems in the JABODETABEK region, which is known for its high tourist activity and consequently high CO_2 emissions. Due to its accelerated growth and potential as a benchmark for the social acceptance of CCUS, this region was selected as a unique case study.

Before the questionnaire was distributed to the participants, it underwent an ethical evaluation and was approved by the Ethics Secretariat of the JEP UKM Department (reference number: UKM/PPI/111/JEP-2023-113). The survey was then emailed to 6000 randomly selected individuals within the JABODETABEK region. The participants had the option to complete the survey at their leisure.

Before starting the survey, participants were informed of the research objectives and asked for their permission. The survey was completed by 500 people from five communities in the region (Jakarta, Bogor, Depok, Bekasi, and Tangerang). The response rate of 8.3% is within the average range for email-distributed surveys.

2.3. Measures

To gauge public opinion on CCUS technologies in Jakarta, Bogor, Depok, Bekasi, and Tangerang, this study used a questionnaire designed by the research team. To construct a prediction model for the adoption of CCUS, this survey was created to gauge the general public's familiarity with and opinion on CCUS technologies. Items from earlier studies on public acceptance of CCUS technologies in various countries were included in the questionnaire, along with items designed by the research team to examine the many dimensions of public acceptance of energy technology.

Baseline questions, CCS/CCU details, awareness and overall assessment, attribute beliefs, acceptance, preferred alternatives, and trust were only some of the topics covered in the questionnaire's several sections. Two paragraphs detailed the essential characteristics of CCS/CCU technologies in the second portion of the questionnaire. Sections ii, iii, and iv of the questionnaire were the meat and potatoes of the study, since they contained most of the items aimed at gauging the level of knowledge of the respondents, emotions, perceptions of benefits and drawbacks, and general dispositions towards them. To assess the reliability of the aforementioned questionnaire, Cronbach's coefficient alpha was used, the results of which indicated a good level of reliability (attitude α = 0.862; beliefs α = 0.750; perceived benefit/cost α = 0.854; trust α = 0.755; emotion α = 0.883; social norm α = 0.766; cognitive dissonance α = 0.722).

2.4. Data Analysis

The structural equation modelling (SEM) approach was used to evaluate the data obtained from this investigation. Structural equation modelling (SEM) analysis investigated the connections between study variables: awareness, general evaluation of CCUS technologies, affect, perception of qualities, benefits and costs, acceptance, preference over other technologies, and trust. The SEM analysis also allowed us to determine the most important individual factors that determine the acceptability of technologies such as CCU and CCS. In addition to structural equation modelling, the study variables were cross-analysed by age, sex, urban/rural residency, and income using descriptive statistics and bivariate correlations. The calculations in the statistical analysis were performed using the Statistical Package for the Social Sciences (SPSS) version 26.

3. Results

3.1. Demographic Characteristics

Participants in the current study were selected using a convenience sampling strategy. A total of 500 people were included in the study, with men making up 49.8% and women accounting for 50.2 percent. The ages ranged widely, with the highest percentage (18.2%) falling in the "young adults" bracket. Those between the ages of 51 and 60 made up the next largest group (17%), followed by those between the ages of 21 and 30 (17.2%), demonstrating a wide spread of ages among the participants.

Most of the respondents said their annual income was less than IDR 5,500,000. Participants with incomes between IDR 2,500,000 (13.6%) and IDR 2,500,000–3,500,000 (10.6%) were the most numerous. These results indicate that the majority of the people who participated in the survey had a modest income. Most of the participants had completed high school (21.2% of the total) or college (21.4%). Less than twenty-one percent of the survey population reported having no formal education. Most of the participants (20%) and those who leased (21.4%) had their own homes, while only a minority (17.8%) lived in family homes. These results indicate that the study sample included people from various backgrounds in terms of housing (see Table 1).

3.2. Level of Awareness towards CCUS Technology

Next, we aimed to assess the respondents' level of awareness regarding CCUS technology. To achieve this, we provided information on CCUS technology and its potential to mitigate climate change and asked participants to evaluate CCU and CCS as alternative solutions to address climate change. We provided comprehensive information about CCUS in an online form created for participants. To measure the participants' awareness of CCUS, we used a 5-point Likert scale, ranging from 1 (very poor) to 5 (very good).

Table 2 and Figure 3, presented above, provide an overview of the responses from the participants regarding their awareness of CCUS technology. The results indicate that most of the participants had a low level of knowledge of CCUS technology. Specifically, more than half of the participants in each area rated their awareness as "very poor" or "poor". The highest percentage of participants who rated their awareness as "very poor" were in Bekasi (47%), followed by Tangerang (33%), Jakarta (27%), Depok (28%), and Bogor (37%). These findings suggest a significant lack of awareness among participants about CCUS technology and its potential to mitigate climate change. More efforts are needed to raise awareness and promote education on this important topic in the areas studied.

3.3. Investigating Fear and Interest Levels among Respondents

As part of our study on CCUS technologies, we sought to dig deeper into how people respond emotionally to this innovative technology. To do so, we asked our participants to rate to what degree the CCUS information fact sheet triggered their fear and interest (see Table 3).

Subjective reactions to CCUS technologies in Jakarta, Bogor, Depok, Bekasi, and Tangerang are shown in the table below. There appears to be a range of feelings towards CCUS technologies among the participants, as evidenced by the results. Participants in Tangerang were more likely to report "very fear" about CCUS technology, while those in Depok were less likely to have such feelings.

Table 1. Sample demographics. Source: own elaboration.

Demographic Factors	Frequency	Percentage	Demographic Factors	Frequency	Percentage
Gender			Income		
Male	249	49.8	<IDR 2,500,000	68	13.6
Female	251	50.2	2,500,000–3,500,000	53	10.6
Age			3,501,000–4,500,000	56	11.2
18–20	91	18.2	4,501,000–5,500,000	51	10.2
21–30	86	17.2	5,501,000–6,500,000	53	10.6
31–40	83	16.6	7,501,000–8,500,000	47	9.4
41–50	82	16.4	8,501,000–9,500,000	75	15
51–60	85	17	9,501,000–10,500,000	49	9.8
>60 years old	73	14.6	>IDR 10,501,000	48	9.6
Educational Status			Residence		
No formal education	105	21	Family house	89	17.8
Primary education/junior high school	87	17.4	Private house	100	20
Senior high school	106	21.2	Rent	107	21.4
Bachelor	95	19	Contract	104	20.8
Postgraduate	107	21.4	Boarding house	100	20
Working Status					
Unemployed	75	15			
A contract in the private sector	77	15.4			
Permanent position in the private sector	87	17.4			
Civil servant	73	14.6			
Self-employed	98	19.6			
Contract in the government	90	18			

Table 2. Level of awareness. Source: own elaboration.

Area	Participants	% of Total Participants	Very Poor (1)	Poor (2)	Moderate (3)	Good (4)	Very Good (5)
Jakarta	220	0.44	60	55	66	11	28
Bogor	65	0.13	24	16	5	14	6
Depok	80	0.16	22	23	24	6	5
Bekasi	85	0.17	40	23	6	10	6
Tangerang	50	0.1	20	13	23	5	7

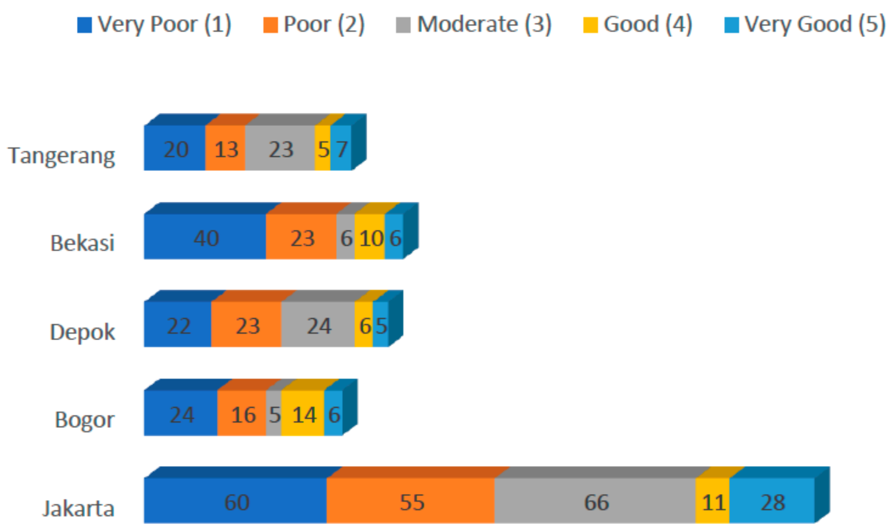

Figure 3. Level of awareness. Source: own elaboration.

Table 3. Fear and interest levels among respondents. Source: own elaboration.

Area	Participants	% of Total Participants	Very Fear (1)	Poor Fear (2)	Not Sure (3)	Interest (4)	Very Interesting (5)
Jakarta	220	0.44	65	40	59	38	18
Bogor	65	0.13	22	15	13	15	7
Depok	80	0.16	13	27	13	10	5
Bekasi	85	0.17	28	27	16	10	4
Tangerang	50	0.1	42	16	18	8	4

The results show that many respondents have serious reservations about using CCUS technology (see Figure 4). This may imply that respondents are aware of the difficulties associated with CCUS technology and that further public education and communication about the advantages of CCUS technologies are required to allay fears about their use. However, research also shows that people are at least somewhat curious about CCUS technologies.

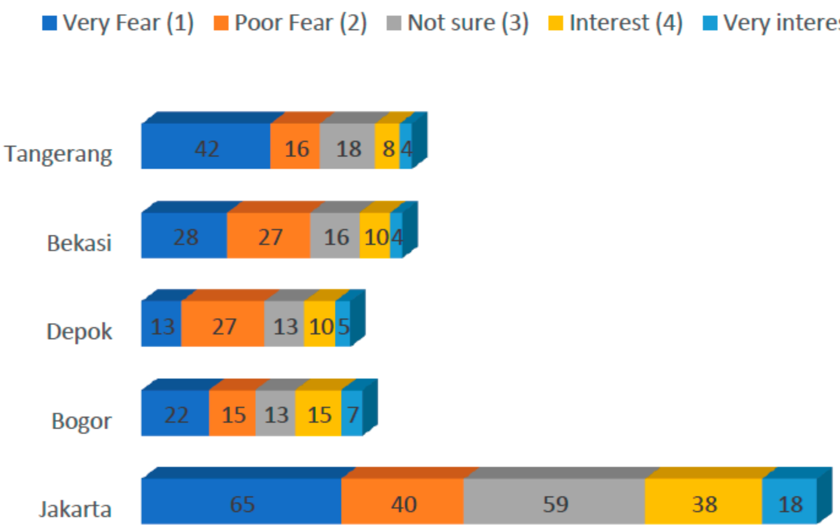

Figure 4. Fear and interest levels among respondents. Source: own elaboration.

3.4. Descriptive Statistics and Independent Sample T-Test Results for Demographic Factors and Social Acceptance of CCUS

The next analysis examined the relationship between demographic factors and social acceptance of carbon capture, utilisation, and storage (CCUS) technology. The analysis involved descriptive statistics for demographic factors and social acceptance scores and independent sample *t*-tests to determine whether there were significant differences in social acceptance scores between different demographic groups. Table 4 provides detailed information on the mean social acceptance scores, standard deviations, *t*-values, *p*-values, and test results for each demographic factor examined.

Table 4. Descriptive statistics and results of the independent sample *t*-test for demographic factors and social acceptance of CCUS. Source: own elaboration.

Demographic Factor	Mean (Males)	Standard Deviation (Males)	Mean (Females)	Standard Deviation (Females)	Score Difference	*t*-Value (Score)	*p*-Value (Score)	Result
Gender	3.97	0.65	3.98	0.64	−0.008	−0.36	0.719	No
Income	4.11	1.07	4.35	1.11	0.261	1.48	0.14	No
Age	4.02	0.81	4.03	0.83	−0.01	−0.39	0.697	No
Educational Status	4.01	0.95	4.05	1.01	0.007	0.34	0.734	No
Residence	3.98	0.69	4.04	0.88	0.053	2.06	0.04	Yes
Working Status	4.01	0.91	4.03	0.94	−0.015	−0.69	0.491	No

The analysis results indicate that there were no significant differences in the social acceptance scores between men and women ($t = -0.36$, $p = 0.719$), income groups ($t = 1.48$, $p = 0.14$), age groups ($t = -0.39$, $p = 0.697$), educational statuses ($t = 0.34$, $p = 0.734$), and working statuses ($t = -0.69$, $p = 0.491$). However, there was a significant difference in social acceptance scores between residents of different areas ($t = 2.06$, $p = 0.04$), and those living in urban areas showed greater social acceptance of CCUS technology than those living in rural areas.

3.5. Exploring the Acceptance of CCUS Technologies

To determine the acceptance of CCUS technologies, the researchers employed a multivariate analysis method using structural equation modelling (SEM) to examine direct and indirect determinants. The researchers proposed a model of acceptance to analyse public acceptance (see Table 5).

Table 5. Total, direct, and indirect standardised effects. Source: own elaboration.

Variable	Direct Effect	Indirect Effect	Total Effect
Attitudes	0.13	0.13 *	0.26 *
Beliefs	0.08	0.10 *	0.18 *
Perceived benefits/costs	0.18		0.18
Trust	0.13	0.13 *	0.26 *
Emotions	0.11		0.11
Social norms	0.05	0.07 *	0.12 *
Cognitive dissonance	-	0.02 *	0.02 *

* significant purpose.

The above table provides an overview of the direct, indirect, and overall effects of several variables on the social acceptance of carbon capture, use, and storage (CCUS) technology. Information was collected by interviewing 500 people and asking them about their thoughts and feelings towards CCUS.

According to the findings, an individual's feelings about CCUS had a direct effect of 0.13 on social acceptance. This indicates that those with more favourable attitudes towards this technology were more inclined to embrace it. Furthermore, attitudes also had a substantial indirect influence of 0.13 through other factors, which brought the total effect of attitudes to 0.26. This suggests that attitudes play a significant role in determining the degree to which CCUS is accepted in society, directly and indirectly, due to other factors.

Furthermore, beliefs about CCUS had a direct effect on social acceptance equal to 0.08 and a substantial indirect effect equal to 0.10, resulting in a total effect equal to 0.18. This suggests that individuals' opinions regarding the possible benefits and risks connected with CCUS are major determining factors in their willingness to accept the technology.

Other variables that have significant total impacts on societal acceptance of CCUS include perceptions of advantages and costs (total effect = 0.18), trust in energy corporations (total effect = 0.26), social norms (total effect = 0.12), and cognitive dissonance (total effect = 0.02). According to the findings, perceptions of the benefits and costs associated with CCUS, trust in the institutions and individuals involved in CCUS, their conformity to social norms, and their ability to reconcile conflicting attitudes and beliefs can play a role in determining whether or not they will accept technology.

4. Discussion

Research on the public assessment of CCS and CCUS is still very limited in developing countries such as Indonesia. However, it is interesting and important for governments and industries to understand public attitudes towards this technology, given its potential economic and environmental impacts if it is applied successfully [32–35]. Furthermore, to date, no studies have focused on targeting public acceptance in developing countries regarding the application of CCUS technology. Therefore, this study aims to fill this gap by analysing the social acceptance of CCUS technology and its relationship with various demographic factors. The results of this study provide information on the factors that influence public acceptance of CCUS technology in Indonesia, which could be used as a basis for policy making and industry practises [34,36–38]. Furthermore, the findings could also contribute to the literature on public attitudes towards emerging technologies in developing countries.

The research shows the importance of comprehending the distinct carbon capture and utilisation (CCU) and carbon capture and storage (CCS) technologies in the process of formulating and executing carbon capture, utilisation, and storage (CCUS) initiatives. In contemporary times, carbon capture and use (CCU) methods have garnered significant interest in mitigating greenhouse gas emissions through the capture and repurposing of carbon dioxide (CO_2) for alternative applications. Carbon dioxide (CO_2) has the potential to serve as a precursor for the synthesis of various chemical compounds, fuels, and building materials. The implementation of CCU technologies holds promise in mitigating emissions and generating new economic prospects and value chains. However, CCU technologies encounter various obstacles, such as exorbitant expenses and technological constraints.

Using carbon capture and storage (CCS) technologies encompasses the capture of CO_2 emissions from various sources, such as industrial processes and power plants, and their storage in geological formations, such as deep saline aquifers or depleted oil and gas reservoirs. Carbon capture and storage (CCS) technology exhibits the capacity to substantially mitigate greenhouse gas emissions originating from sizeable stationary sources, including power plants. This technology has already been implemented in numerous large-scale initiatives across the globe. Notwithstanding its potential benefits, CCS encounters various obstacles, such as exorbitant expenses, technological limitations, and societal approval.

To achieve the successful development and implementation of carbon capture, use, and storage (CCUS) programmes, a comprehensive and collaborative approach is necessary. This approach should consider the distinctive benefits and obstacles associated with each CCU and CCS technology. Collaboration among policymakers, industry stakeholders, and the general public is imperative to advance the growth and implementation of these technologies as a feasible approach to addressing the issue of climate change. Furthermore, it is imperative to continue to carry out research and development efforts to tackle the technological and economic obstacles linked to carbon capture and utilisation (CCU) and carbon capture and storage (CCS) and to guarantee their sustained feasibility.

The findings of this report indicate that, based on the survey results, only a small number of the respondents are aware of CCUS technology. This is followed by fear among the public about implementing this technology. This suggests that public knowledge of the implementation of CCUS technology is still weak, even though it could provide positive environmental benefits. These results are very similar to previous reports by Ericson et al. [39] or Porse et al. [40], which state that public awareness and knowledge of CCUS technology are limited.

CCUS technology, which stands for carbon capture, use, and storage, is a technology that aims to capture carbon dioxide emissions from various sources, such as power plants and industrial processes, and then store or use them for other purposes, such as improved oil recovery or chemical production [41–43]. Despite its potential benefits in reducing greenhouse gas emissions, public awareness and acceptance of this technology have been limited. The low level of awareness among the public regarding CCUS technology suggests a need for greater public education and engagement to increase awareness and understanding of the technology. This could involve government, academic institution, and industry stakeholder outreach campaigns to provide information and increase public participation in developing and implementing CCUS technology.

Additionally, addressing public fears and concerns about the implementation of CCUS technology is crucial to increasing public acceptance of the technology. This could involve transparent communication about the risks and benefits of the technology, as well as efforts to address any potential negative impacts on the environment and public health.

The research findings indicate that most of the respondents who participated in this study have a negative attitude towards CCUS technology. This is supported by the respondents' low awareness and high level of fear about implementing this technology. These results contradict previous research by Fernandez [16], in which respondents had a supportive attitude towards the implementation of CCUS because it was believed to provide environmental benefits. This difference may be due to the low level of knowledge about this technology. CCUS is perceived as dangerous and lacking innovation and not providing economic benefits to society, making it likely that rejection occurs in developing regions.

Increasing public knowledge and understanding of CCUS technology is important in addressing this issue. Efforts to increase public awareness of the potential benefits of this technology could include providing information on how CCUS can help reduce greenhouse gas emissions and mitigate climate change, as well as highlighting its economic benefits. Additionally, it is important to address concerns about the potential risks and negative impacts of CCUS on the environment and public health and to provide transparent information to increase public trust in technology.

In addition, it is important to engage the public in the development and implementation of CCUS technology. This could involve public participation in decision-making processes, such as consultations and public hearings, to ensure that the concerns and interests of the public are taken into account [23,41,44,45]. This would help build trust and confidence in this technology among the public and foster a more positive attitude towards its implementation.

Furthermore, another finding of this study is the attitude of the respondents towards CCUS technology. The analysis showed that the low acceptance of CCUS technology is due to the lack of knowledge about the technology, which is consistent with previous research by Oltra et al. [11]. Public concern is also a determining factor in the acceptance of technology, where when the public perceives that CCUS technology will provide better environmental safety, they tend to choose it as an alternative technology that provides better environmental protection [1,46,47]. Furthermore, differences in the sociodemographic characteristics of the respondents, who come from developing countries, also contribute to the rejection and low awareness of CCUS technology [14]. At the national level, there is a tendency for CCUS opponents to report less interest in the technology, as well as a higher level of fear associated with CCS relative to supporters. Opponents perceive CCS as more dangerous and less beneficial to the economy than supporters of the technology. They tend to have lower levels of trust in energy companies.

To address these concerns, providing accurate and transparent information about the benefits and risks of CCUS technology to the public is important. This can be achieved through public education and awareness campaigns and the participation of local communities in the development and implementation of CCUS projects. Involving local communities in decision making and addressing their concerns can help build trust and acceptance of this technology and ensure that their interests and concerns are considered. Furthermore, it is important to involve stakeholders from different sectors, including industry, government, and civil society, in discussions about CCUS technology to ensure that diverse perspectives are represented and to promote dialogue and collaboration.

An intriguing finding of this research is that the perception of risk and environmental damage, the perception of economic benefits for the region, and previous pro-technology attitudes are the most important individual-level predictors of CCUS adoption at the local level. This study's model does not entirely explain the acceptance of CCUS, but it aids in understanding its components. Other variables that were not taken into account in the study may explain CCUS acceptance. Furthermore, attitudes and opinions may be unstable and susceptible to contextual factors.

In general, our data indicate the need for (I) developing a positive CCUS project vision that is aligned with the community's values, expectations, and aspirations; (II) increasing local involvement in the project; (III) providing local benefits; (IV) integrating sustainability with existing community structures; and (V) ensuring effective communication and participation.

5. Conclusions

According to the results, people in developing nations such as Indonesia know little about CCUS technology. Because of the public's lack of understanding, CCUS technology is often met with scepticism and hostility, which threatens the effectiveness of CCUS initiatives. Therefore, outreach programmes by the government, academic institutions, and industry stakeholders are needed to educate the public and improve people's knowledge and understanding of technology.

In order to increase the public acceptance of CCUS technology, it is essential to address public anxieties and concerns about its implementation. This could include making people aware of the potential hazards and benefits of the technology and working to mitigate any adverse effects it may have on the environment or people's health. Further, public participation in CCUS research and implementation is essential for gaining the public's trust and confidence in the technology and encouraging a more optimistic outlook on its eventual deployment.

This study suggests that public awareness and understanding of CCUS technology is low in developing countries, such as Indonesia. To improve public acceptance of CCUS, it is essential to address public concerns and anxieties about the technology while providing accurate and complete information on its potential benefits and limitations. The study identified three concrete CCUS technologies: carbon capture, carbon storage, and carbon utilisation, each with advantages and challenges. Carbon capture technology can be energy-intensive and costly, while carbon storage technology may be limited by the availability of suitable storage sites and the risk of carbon leakage. Carbon utilisation technology may require significant infrastructure investments and could compete with other uses of captured carbon dioxide.

To enhance the public's acceptance of these CCUS technologies, outreach programmes by the government, academic institutions, and industry stakeholders are needed to educate the public and improve people's knowledge and understanding of the technology. Moreover, public participation in research and implementation is essential to gain public trust and confidence in the technology.

Finally, the public must receive complete and accurate information on the advantages and disadvantages of CCUS technology. Educating the public and receiving their input on the design and implementation of CCUS programmes are two ways to achieve this goal. Discussions about the benefits of CCUS technology should include representatives from various sectors, not just the private sector, government, and the nonprofit sector. These actions have the potential to raise public awareness of CCUS technology, which, in turn, could help reduce greenhouse gas emissions and slow the rate of climate change.

Despite the strengths of this study, several limitations need to be acknowledged. First, the sample size was relatively small and consisted mainly of participants from one geographic region, which may limit the generalisability of the findings to other populations. Second, the study relied on self-reported data, which may be subject to response and social desirability biases.

Several areas of future research could be based on the findings of this study. First, larger-scale studies with more diverse populations and geographic regions could help confirm the results' generalisability. Second, future research could investigate the possible mediating or moderating effects of other variables that may influence the relationship between X and Y. Third, longitudinal studies could help establish the causal relationship and add more variables that can determine human acceptance of new technology.

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