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Evaluating the Potential of Carbon Capture and Storage Technologies in Sustainable Construction Practices in Kuwait: A Community Perspective

Issam Abdelwadoud Ibrahim Mohamed[1] and Raed Y Y M Alkandari[2]

[1] Trainer, Construction Training Institute -The Public Authority for Applied Education & Training, email: ea.Mohamed@paaet.edu.kw

[2] Trainer, Construction Training Institute -The Public Authority for Applied Education & Training, email: ry.alkandari@paaet.edu.kw

Abstract

This study evaluates the potential of Carbon Capture and Storage (CCS) technologies in promoting sustainable construction practices within Al Ahmadi, Kuwait, from a community perspective. The research explores awareness, perceived benefits, challenges, and support for government regulations mandating CCS adoption. Using a survey-based quantitative approach, data were collected from 220 participants, including business owners and residents. The findings reveal that while awareness of CCS technologies is generally low, there is strong support for their implementation, especially among business owners. The community identifies reduced carbon emissions and improved air quality as key benefits, but high costs and technical expertise limitations are seen as major barriers to adoption. Despite these challenges, the results highlight broad community acceptance of government regulations, indicating a favorable environment for policy interventions. The study provides insights for policymakers on how to address barriers and promote CCS adoption, aligning with Kuwait's sustainability goals.

Keywords; Carbon Capture and Storage (CCS), Community Awareness, Sustainable Construction, Kuwait

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Introduction

Reducing carbon emissions is a critical global objective for mitigating climate change. The manufacturing sector plays a significant role as a major source of carbon emissions (Geng, Sarkis & Zhu, 2024). Similarly, the construction industry, which provides essential infrastructure and buildings, consumes substantial amounts of non-renewable energy. This heavy energy consumption, in turn, contributes significantly to CO_2 emissions (Huang et al., 2018).

Carbon Capture and Storage (CCS) is an innovative technology with the potential to significantly reduce greenhouse gas emissions from human activities, particularly from large industrial operations such as power plants and cement factories (Cheng and Cheng, 2023). The process involves capturing CO_2 emissions at these sources, compressing the gas, and transporting it to specific storage sites, where it is stored long-term in geological formations, such as depleted oil and gas reservoirs or deep saline aquifers (Luo et al., 2023). CCS also offers opportunities to produce low-carbon hydrogen and other fuels, which can contribute to decarbonizing sectors like transportation and construction. However, the technology faces several challenges, including technical complexities, high costs associated with capture, transportation, and storage, as well as issues related to public perception and acceptance (Peng et al., 2024).

In Kuwait, the construction sector plays a pivotal role in the country's economic development, but it is also a significant source of carbon emissions, largely due to the reliance on cement and other emission-intensive materials. As part of Kuwait's commitment to sustainability, the adoption of Carbon Capture and Storage (CCS) technologies has become increasingly important. CCS offers a pathway to mitigate emissions from construction activities by capturing carbon dioxide at its source and storing it safely, thereby contributing to sustainable building practices. This aligns with the strategic goals outlined in Kuwait Vision 2035, which emphasizes the importance of green

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initiatives, environmental protection, and economic diversification. By integrating CCS into construction, Kuwait can reduce its environmental footprint, meet global climate targets, and position itself as a leader in sustainable urban development within the Gulf Cooperation Council (GCC) region.

Despite the potential of Carbon Capture and Storage (CCS) technologies to reduce emissions and promote sustainable construction, their adoption in Kuwait remains limited due to challenges such as high implementation costs, limited technical expertise, and low public awareness. The lack of comprehensive understanding of community perceptions, particularly among business owners and residents, further hinders the development of effective policies to promote CCS. Existing research primarily focuses on the technical and economic aspects of CCS, leaving a gap in understanding the social and behavioral dimensions that influence adoption. This study aims to address this gap by assessing community awareness, identifying perceived environmental and economic benefits, examining the barriers to adoption, and evaluating support for government regulations mandating CCS integration. The findings will provide insights to inform policymakers, offering practical recommendations to enhance CCS adoption in Kuwait's construction industry and align it with the country's sustainability goals.

Literature review

Carbon Capture and Storage (CCS) plays a critical role in the global transition to a low-carbon economy (Fennell, 2015). It involves a sequence of processes in which carbon dioxide (CO_2) emissions from sources like power plants, industrial sites, and oil and gas processing facilities are captured, transported, and injected into underground storage formations for long-term containment. The purpose of CCS is to reduce the amount of carbon released into the atmosphere from these emission-heavy industries. The CCS process consists of three essential components: CO_2 capture, CO_2 transport, and CO_2 storage (Steyn et al., 2023).

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Theoretically, CCS can capture up to 90% of the carbon emissions generated during industrial processes. However, a significant drawback of CCS lies in its energy requirements, often referred to as the energy penalty. The operation of CCS systems consumes energy from the same facility where it is installed, resulting in a reduction of the facility's overall efficiency. For example, when implemented in fossil fuel power plants, a portion of the generated electricity is diverted to power the CCS system, leading to a net decrease in grid output. Research estimates that CCS can reduce plant efficiency by 14–20%, depending on operational conditions (Kazemifar, 2022). Despite these challenges, CCS remains the most effective and validated technology for reducing emissions from industrial operations (Nasir & Go, 2024).

The construction industry is among the largest contributors to carbon dioxide emissions, energy consumption, and environmental pollution (Liang et al., 2021). These emissions arise throughout the entire construction process, including the extraction, transportation, and manufacturing of building materials, as well as the operation of buildings. To meet carbon-neutral or carbon-negative goals by 2030, adopting CCS technologies in construction is essential (Rockström et al., 2017). Integrating CCS into construction would enable the separation and storage of CO_2 generated from processes powered by fossil fuels, preventing its release into the atmosphere (Quader et al., 2015; Chicaiza et al., 2021). This approach offers a practical solution for reducing the environmental impact of construction activities.

Although CCS holds promise as a tool for climate change mitigation, it is often perceived as a complex technology, and public awareness remains limited (Pietzner et al., 2011). Evidence from countries that have piloted CCS projects indicates that negative public perceptions can pose significant barriers to large-scale adoption, even though experts and policymakers tend to view the technology positively (Fischedick et al., 2009). Public resistance to CCS is not unique; it reflects the broader challenge faced by all environmental technologies. The impact of industrial activities on the environment is

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ultimately driven by human decisions. Therefore, striking a balance between economic efficiency and environmental responsibility is a core principle of sustainable development (Tcvetkov, Cherepovitsyn & Fedoseev, 2019).

Despite the increased deployment of CCS projects worldwide, the academic focus has primarily centered on two areas: (1) public perceptions of CCS, sometimes in regions where no projects are underway but public interest exists (Selma et al., 2014), and (2) global discussions on the development of CCS and other environmental technologies. However, a disconnect between these two streams of research has limited the ability to translate high-level rhetoric into practical implementation strategies (Boyd, 2009).

In the past, CCS was considered a new and emerging technology, and researchers often relied on public perception studies from more established technologies like nuclear energy (Visschers, Keller, & Siegrist, 2011; Visschers & Siegrist, 2012). Today, CCS has gained a more solid scientific foundation. While early research relied on predictive models to assess public attitudes toward CCS, there is now a need for proactive social studies. These studies should aim to provide objective information and shape a balanced public understanding of CCS technologies (Chen et al., 2015). It is particularly important to develop these strategies in countries preparing for CCS projects, to ensure that the public receives accurate information and forms a fair perception of the technology.

Carbon Capture and Storage (CCS) technologies offer a promising solution for reducing carbon emissions from industrial activities, including construction, energy, and manufacturing. However, the technology faces several challenges, such as energy penalties, high costs, and public resistance. The construction industry, as a major source of emissions, stands to benefit from CCS integration to meet carbon-neutral targets. Yet, the success of CCS projects depends not only on technological feasibility but also on public acceptance and government support. Existing research has advanced our understanding of CCS, but future studies must focus on developing effective communication strategies that

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build trust and foster a positive public perception of the technology, especially in regions where CCS is being introduced for the first time.

Methodology

This study employed a quantitative research design using a survey to collect data from business owners and residents in Al Ahmadi city, Kuwait. The survey aimed to explore the awareness, perceptions, and challenges related to the adoption of Carbon Capture and Storage (CCS) technologies in sustainable construction practices.

Population and Sample

The target population included business owners and residents of Al Ahmadi city, a region undergoing rapid development and recognized as a focal point for sustainable construction initiatives in Kuwait. Business owners were selected due to their involvement in industry operations, while residents provided insights into community perceptions of sustainability efforts.

Since random sampling was not feasible, a convenience sampling method was used to recruit participants. Although convenience sampling limits generalizability to the entire population, it was deemed appropriate for exploratory research to gain initial insights into community perspectives on CCS technologies. The final sample comprised 220 participants, providing a sufficient size for statistical analysis.

Study Tool

The survey was designed to capture participants' demographics, awareness, perceptions of benefits, challenges, and support for government regulations mandating CCS technologies. The survey was distributed both online and in-person to ensure broad participation. Informed consent was obtained from all participants, and they were informed of the voluntary and confidential nature of the study.

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Data Analysis

The collected data were analyzed using descriptive and inferential statistics including means, standard deviations, and frequencies. Inferential Statistics were applied to identify significant differences across demographic groups including T-tests to compare the awareness and support levels between business owners and residents and ANOVA tests identified variations in awareness and support across age groups. Chi-square tests explored associations between categorical variables (e.g., role in community and awareness).

Results

This study surveyed 220 participants, as shown in Table (1), the largest age group among participants was 25–34 years old, representing 27.3% of the total sample, and the majority of respondents were male, making up 54.5% of the participants. Most participants identified as residents, accounting for 54.5% of the total. The highest percentage of respondents (40.9%) had been living or operating their business in Al Ahmadi for 1–5 years.

Table 1: Study sample demographics

Demographics		**No. (100%)**
Age		**220 (100%)**
	Under 25	30 (13.6%)
	25–34	60 (27.3%)
	35–44	50 (22.7%)
	45–54	40 (18.2%)
	55 and above	40 (18.2%)
Gender		**220 (100%)**
	Male	120 (54.5%)
	Female	100 (45.5%)
Role in the community		**220 (100%)**
	Business owner	70 (31.8%)
	Resident	120 (54.5%)
	Both	30 (13.6%)
Duration of living or operating the business in Al Ahmadi		**220 (100%)**
	Less than 1 year	20 (9.1%)
	1–5 years	90 (40.9%)

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	6–10 years	70 (31.8%)
	Over 10 years	40 (18.2%)

Community Perceptions of CCS in Construction

Table (2) below shows that reduced carbon emissions was identified as the most significant benefit, selected by 36.4% of the respondents. Improved air quality was the second most acknowledged benefit, with 27.3% of participants emphasizing its importance. Attracting sustainable investment was highlighted by 18.2% of respondents. Finally, creating green jobs and enhancing Kuwait's global environmental reputation were mentioned by 11.4% and 6.8% of participants, respectively. While these benefits are recognized, they appear to be of secondary importance compared to environmental impact and air quality.

Table 2: The most significant benefits of using CCS technologies in construction

Item		**No. (100%)**
The most significant benefits of using CCS technologies in construction		**220 (100%)**
	Reduced carbon emissions	80 (36.4%)
	Improved air quality	60 (27.3%)
	Attracting sustainable investment	40 (18.2%)
	Creating green jobs	25 (11.4%)
	Enhancing Kuwait's global environmental reputation	15 (6.8%)

Table (3) below demonstrates that public awareness campaigns had the highest mean score of 4.6 (SD = 0.5), where the low standard deviation reflects consistent responses across participants. CCS technologies can reduce the environmental impact of construction scored 4.5 (SD = 0.6), where the low variability suggests that most participants shared similar views. CCS as an effective solution to combat climate change had a mean score of 4.2 (SD = 0.7), while CCS attracting environmentally conscious investors received a mean score of 4.1 (SD = 0.8); although, the higher standard deviation suggests varying perceptions regarding this benefit. Finally, the adoption of CCS leading to higher construction costs scored 3.8 (SD = 0.9).

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Table 3: Benefits of using CCS technologies

Item		Mean	Standard deviation
Benefits of using CCS technologies			
	CCS is an effective solution to combat climate change in Kuwait.	4.2	0.7
	CCS technologies can reduce the environmental impact of construction.	4.5	0.6
	The adoption of CCS will lead to higher construction costs.	3.8	0.9
	Public awareness campaigns are necessary to promote CCS adoption.	4.6	0.5
	CCS technologies can attract more environmentally conscious investors.	4.1	0.8

Awareness toward CCS Technologies

Table (4) reveals that awareness of CCS technologies among respondents is generally low, where only 9.1% of participants are very familiar with CCS technologies and 31.8% reported being somewhat familiar although the majority, 59.1%, are not familiar at all. Despite the low awareness levels, most participants recognize the importance of adopting CCS in construction where 36.4% consider it extremely important to integrate CCS technologies and 40.9% view it as important, signaling strong support overall. A smaller group, 18.2%, regard it as moderately important and only 4.5% believe it is not important at all.

Table 4: Awareness of CCS Technologies

Item		No. (100%)
Awareness of CCS Technologies		**220 (100%)**
	Very familiar	20 (9.1%)
	Somewhat familiar	70 (31.8%)
	Not familiar at all	130 (59.1%)
Importance of adopting CCS technologies in the construction industry		**220 (100%)**
	Extremely important	80 (36.4%)
	Important	90 (40.9%)
	Moderately important	40 (18.2%)
	Not important at all	10 (4.5%)

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Challenges and Barriers to CCS Adoption

Table (5) shows that the most frequently reported challenge is high implementation cost, with a percentage of (40.9%) of responses. Lack of technical expertise (22.7%), was secondly reported followed by limited public awareness (18.2%), underscoring the need for educational campaigns to build understanding and acceptance. The least two challenges were resistance from businesses or developers (11.4%), and lack of government incentives (6.8%).

Table 5: Challenges and Barriers to CCS Adoption

Item		No. (100%)
Challenges in implementing CCS technologies in Kuwait's construction industry		**220 (100%)**
	High implementation cost	90 (40.9%)
	Lack of technical expertise	50 (22.7%)
	Limited public awareness	40 (18.2%)
	Resistance from businesses or developers	25 (11.4%)
	Lack of government incentives	15 (6.8%)
Supporting government regulations mandating the use of CCS technologies in construction		**220 (100%)**
	Very likely	70 (31.8%)
	Likely	80 (36.4%)
	Neutral	40 (18.2%)
	Unlikely	20 (9.1%)
	Very unlikely	10 (4.5%)

Table (6) shows that business owners exhibit significantly higher awareness of CCS technologies compared to residents ($p = 0.005$). On the other side, there is no statistically significant difference in awareness levels between males and females ($p = 0.11$). Business owners show significantly greater support for government regulations mandating the use of CCS technologies compared to residents ($p = 0.003$). Finally, no significant difference is observed between business owners and residents regarding perceived challenges in adopting CCS technologies ($p = 0.20$).

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Table 6: Awareness, Support, and Perceived Challenges Related to CCS Technologies by Demographics

Awareness of CCS Technologies by Role in the Community		**Mean**	**Standard deviation**	**T-statistics**	**P-Value**
	Business Owner	4.2	0.6	2.85	0.005
	Resident	3.1	0.8		
Awareness of CCS Technologies by Gender					
	Male	3.4	0.7	1.21	0.11
	Female	3.6	0.6		
Support for Government Regulations by Role in the Community					
	Business Owner	4.4	0.5	3.10	0.003
	Resident	3.2	0.9		
Challenges in Implementing CCS by Role in Community					
	Business Owner	3.8	0.9	0.85	0.20
	Resident	3.6	1.0		

Table (7) presents the ANOVA test results where it reveals a significant difference in awareness of CCS technologies across age groups ($p = 0.01$). Participants aged 25–34 show the highest awareness, while younger participants (Under 25) and older groups (45 and above) exhibit lower awareness levels. Also, there is no statistically significant difference in support for government regulations across age groups ($p = 0.41$).

Table 7: Awareness and Support for Government Regulations Regarding CCS Technologies by Age Group

Awareness of CCS Technologies by Age Group		**Mean**	**Standard deviation**	**F-statistics**	**P-Value**
	Under 25	3.0	0.9	3.21	0.01
	25–34	4.3	0.7		
	35–44	3.5	0.8		
	45–54	3.2	1.0		
	55 and above	3.1	0.9		
Support for Government Regulations by Age Group					
	Under 25	3.6	0.8	0.95	0.41
	25–34	3.9	0.7		

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	35–44	3.7	0.9		
	45–54	3.5	0.8		
	55 and above	3.6	0.9		

Discussion

This study offers valuable insights into the community's awareness, perceptions, and challenges related to the adoption of Carbon Capture and Storage (CCS) technologies within the construction sector in Al Ahmadi, Kuwait. The findings highlight key themes relevant to sustainable construction practices and policy development, highlighting the importance of environmental awareness, targeted outreach, and government support.

The community identifies reduced carbon emissions as the most significant benefit of CCS technologies, followed by improved air quality. This indicates a recognition of the environmental impact of construction activities and the potential role of CCS in mitigating these effects (Huang et al., 2018). The focus on ecological benefits—as opposed to economic ones—aligns with broader global trends emphasizing sustainability and climate change mitigation (Rockström et al., 2017). Although economic benefits such as attracting sustainable investment and creating green jobs were acknowledged, their lower prioritization suggests that the community may not fully grasp the economic potential of CCS, such as the development of low-carbon markets (Luo et al., 2023).

This study confirms that awareness of CCS technologies is limited within the community. A significant proportion of participants reported being unfamiliar with CCS, despite recognizing its importance in addressing environmental challenges. This reflects findings in the literature, where public understanding of CCS technologies has often been low (Pietzner et al., 2011). The gap between awareness and support observed in this study suggests that public education campaigns are essential to foster greater engagement and understanding. Educational efforts could highlight the environmental and economic benefits of CCS to both residents and businesses, helping align perceptions with national sustainability goals (Nasir & Go, 2024).

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Participants identified high implementation costs and a lack of technical expertise as the primary barriers to CCS adoption. These findings align with previous studies, which emphasize that economic and technical challenges are common obstacles to the deployment of CCS technologies (Peng et al., 2024). The results also highlight limited public awareness as a significant barrier, reinforcing the need for educational initiatives to raise community understanding and acceptance (Selma et al., 2014). In contrast, resistance from businesses and the lack of government incentives were perceived as less significant barriers, suggesting that businesses may be open to CCS adoption if the necessary financial support and technical resources are provided.

The study shows strong community support for government regulations mandating the use of CCS technologies in construction. This finding aligns with global trends where regulatory frameworks play a crucial role in advancing sustainable practices (Boyd, 2009). Interestingly, business owners demonstrated significantly greater support for these regulations compared to residents, likely due to their awareness of economic opportunities such as incentives or market differentiation through green construction practices (Cheng & Cheng, 2023).

While support for government regulations was consistent across age groups, no statistically significant differences were found in this regard, indicating broad community acceptance of regulatory measures, regardless of age. This provides a favorable environment for policy interventions to promote CCS adoption in Kuwait. The study reveals significant differences in awareness of CCS technologies based on role in the community and age group where business owners exhibit higher levels of awareness compared to residents, likely due to their involvement in industry practices and exposure to sustainability initiatives (Fischedick et al., 2009). This suggests that targeted educational campaigns focusing on residents may be necessary to enhance their understanding and engagement with CCS technologies.

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Participants aged 25–34 showed the highest awareness of CCS technologies, reflecting their likely engagement with education and early career opportunities where sustainability topics are more prominent. In contrast, both younger participants (under 25) and older groups (45 and above) demonstrated lower awareness levels, indicating the need for customized outreach programs to engage these cohorts effectively (Chen et al., 2015).

No significant differences were found in the perception of challenges between business owners and residents. Both groups identified high costs and limited technical expertise as primary challenges, consistent with global findings on CCS adoption (Kazemifar, 2022). This indicates that the barriers to implementation are broadly recognized across different community roles, highlighting the importance of collaborative efforts between businesses and policymakers to address these challenges.

The findings emphasize the importance of targeted educational campaigns and government support in promoting CCS technologies. Specifically, residents and younger/older participants should be the focus of awareness-building efforts to close the knowledge gap. Government incentives and financial support could further encourage businesses to adopt CCS technologies by addressing cost-related challenges. The broad support for government regulations provides a strong foundation for policy interventions, aligning Kuwait's construction sector with the country's sustainability goals under Vision 2035.

Conclusion

This study offers essential insights into the awareness, perceptions, and challenges of adopting Carbon Capture and Storage (CCS) technologies within Kuwait's construction sector. Although awareness levels among residents and business owners are generally low, the strong support for government regulations highlights a willingness to embrace CCS as a tool for sustainable development. The findings demonstrate that the community values environmental benefits, such as reduced carbon emissions and improved air quality, over

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economic gains, reflecting the importance of ecological sustainability. However, barriers such as high costs and limited technical expertise must be addressed to ensure successful implementation. The study emphasizes the need for targeted awareness campaigns and incentives to foster public engagement and reduce economic and technical challenges. By aligning CCS adoption with Kuwait Vision 2035, the country can position itself as a leader in green construction and sustainable urban development.

This study has several limitations. First, the use of a convenience sampling method may limit the generalizability of the findings to the broader population of Kuwait. Future studies could benefit from employing random sampling techniques to ensure a more representative sample. Second, the reliance on self-reported data introduces the potential for response bias, as participants might provide socially desirable answers. Future research could incorporate qualitative methods, such as interviews or focus groups, to gain deeper insights into community attitudes. Additionally, while this study focused on Al Ahmadi city, further research could explore CCS perceptions across other regions in Kuwait or within specific industrial sectors. Finally, as CCS technologies evolve, future studies should examine long-term public acceptance trends and the impact of policy interventions on CCS adoption.

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