

Evaluating the Feasibility of Carbon Capture and Storage: A Comparative Case Study of China and Norway

Yunxin Wang

*Shanghai Pinghe school, Shanghai, China
yunxinwang0216@gmail.com*

Abstract. With increasing global pressure to achieve carbon neutrality, Carbon Capture and Storage (CCS) has been widely recognized as a key technology for mitigating emissions in hard-to-abate sectors. This study evaluates the feasibility of CCS through a comparative case analysis of the Zhengning project in China and the Sleipner project in Norway. Based on a techno-economic-institutional analytical framework, the study examines CCS deployment from three dimensions: technological performance, economic viability, and institutional conditions. The findings indicate that while CCS technologies are relatively mature and capable of large-scale emission reduction, their economic sustainability remains highly dependent on policy support, particularly carbon pricing mechanisms. In addition, geographical factors such as source–sink matching significantly influence project feasibility and scalability. The comparison further reveals that successful CCS deployment requires the alignment of technology, market incentives, and regulatory frameworks. While the Norwegian case demonstrates a policy-driven model supported by carbon taxation, the Chinese case highlights the challenges of cost recovery in the absence of stable market mechanisms. This study contributes to the understanding of CCS as a context-dependent solution and emphasizes the need for integrated strategies that combine technological innovation with supportive policy design.

Keywords: Carbon Capture and Storage, techno-economic analysis, feasibility, carbon neutrality, case study

1. Introduction

Over the last several decades the global carbon dioxide (CO₂) emissions have only been on the increase due to industrialization, urbanization and the constant dependence on fossil fuels [1]. Although the world is putting more effort towards reducing the effects of climate change through the United Nations Framework Convention on Climate Change and treaties like the Paris Agreement, net-zero emissions is still a major challenge to both developed and the developing economies [2]. Specifically, so-called hard-to-abate industries, such as steel, cement, and chemical industries, have structural and technological barriers that restrict the applicability of traditional decarbonization initiatives, such as electrification or renewable energy replacement. Carbon Capture and Storage (CCS) has taken on a pivotal role in this regard as a technological route towards deep decarbonization [3]. CCS makes it possible to capture the emission of CO₂ at its origin, transport it

and store it permanently in underground geological structures, thus avoiding its emission into the air. Its strategic potential is that it can tackle emissions that are otherwise hard to remove or expensive to remove and so should be used alongside renewable energy transitions, and not as a solution in its own right. Because of this, CCS has been integrated as part of national and international climate roadmaps as an enabling technology of transition.

Nevertheless, the mass application of CCS has a number of critical issues, such as high costs of capital and operation, great additional energy needs (the energy penalty), and uncertainty in total carbon efficiency [4]. These issues have cast doubt on its economic feasibility and long-term environmental performance, and prompted the need to consider CCS as reducing emissions, but also as a cost-effective, energy-efficient technology.

It is against this backdrop that the incorporation of CCS in low-carbon transition pathways is subject to the need to strike a balance between cost, energy consumption and environmental performance. This question is answered in this paper in a case study format by exploring exemplary projects of CCS to understand their costing, energy demands, and carbon reduction performance. Through the comparison of the various industrial settings and technological set ups, the study will determine practicality and strategic importance of CCS in the attainment of long term carbon neutrality objectives.

2. Literature review

2.1. Classification of CCS technologies

The technologies of Carbon Capture and Storage (CCS) can be generally divided into four key groups depending on the method of capture: pre-combustion capture, post-combustion capture, oxy-fuel combustion and Direct Air Carbon Capture and Storage (DACCS) [5]. Pre-combustion capture is the process of capturing CO₂ before fuel combustion, which is commonly achieved by gasifying fuels, and is used in integrated gasification combined cycle (IGCC) systems [5]. By contrast, post-combustion capture captures CO₂ following combustion, and is more flexible to the current industrial plants because of its retrofit capability. In oxy-fuel combustion, the capture of CO₂ is achieved by burning fuel under high purity oxygen atmosphere which results in the generation of a flue gas with high CO₂ content making the separation process easier. Most recently, DACCS has become a negative emissions solution, directly capturing CO₂ in the atmosphere, but is still in a very early phase of implementation because of its energy and cost consumption [6].

Current literature tends to point out trade-offs between these technologies in regard to capture efficiency, energy usage, and sector applicability. Post-combustion capture is usually thought to be the most versatile, but pre-combustion and oxy-fuel systems could be more efficient in particular industrial conditions. Despite its technological potential, DACCS is generally thought to be immature and more resource-intensive.

2.2. Techno-economic analysis of CCS

A significant amount of literature has been devoted to the techno-economic performance of CCS, especially cost estimation, learning curves, and value assessment [3]. The cost analyses often differentiate between capital expenditure (CAPEX), operational expenditure (OPEX) and the incremental costs of transporting and storing CO₂ [7]. In these studies, capture processes are always found to be the most costly part of the CCS value chain. The studies on learning curves indicate that the costs could decrease with time as the deployment increases and the technological advancement

moves [8]. The cost reduction rate, however, is unknown and very much reliant upon policy support, market conditions, and cumulative installed capacity.

Also in this regard, the value assessment studies stress that economic viability of CCS is highly dependent on the carbon pricing mechanisms, regulatory incentives and availability of revenue streams like carbon credits. The CCS projects in most cases fail to meet the financial viability without adequate policy support, especially when compared to other low-carbon technologies.

2.3. CCS deployment feasibility

The technological, geographical, and institutional feasibility of CCS has been extensively studied. Technological readiness Most of the CCS elements, including capture, transport, and storage are regarded as mature at the individual level, although there is no extensive integration of the CCS [9]. Geographical viability is also associated with source-sink matching that is the spatial correspondence between the CO₂ emission sources and appropriate geological storage locations [10]. Research shows that teardrops between emission hubs and the storage capacity may lead to a considerable rise in transport costs and reduce the potential to deploy. The policy and institutional factors are also crucial [10]. The implementation of CCS projects is affected by regulatory frameworks, liability concerns, social acceptance, and long-term monitoring needs. The absence of clear and consistent policy backing is a major obstacle to mass adoption in many areas.

2.4. Research gaps

In general, the literature indicates that there is a wide agreement that CCS is a necessary technology to achieve deep decarbonization, especially in hard-to-abate sectors. Nonetheless, there are still major controversies on its economic competitiveness, long-term environmental efficiency, and position compared to other mitigation measures like renewable energy and electrification.

The main areas of contention are that CCS is expensive and energy intensive, there is uncertainty about the long-term security of long-term storage, and there exists the risk that the implementation of CCS will slow the shift to more sustainable energy systems.

Although a lot of research has been done, there are still a number of gaps. To begin with, it is required to conduct further empirical studies that would consider the performance of CCS in the real world in various industrial settings. Second, there are still few integrated assessments that would simultaneously take into account the cost, energy efficiency, and carbon mitigation outcomes. Third, the nature of interaction between technological development and policy design needs to be explored further to gain a clearer picture of the ways in which institutional framework can facilitate or restrict the deployment of CCS.

3. Research framework

To provide conceptual clarity, this paper first defines some of the key terms that will be used in the analysis. Carbon Capture and Storage (CCS) refers to such technologies that capture carbon dioxide (CO₂) that the industries or energy production produce and transport it to the long-term storage facility, typically the geological structure. The Carbon Capture, Utilization and Storage (CCUS) is an enhancement of this concept since it also involves the use of the captured CO₂ in the industry therefore providing a potential economic advantage.

Within the context of this paper, economic viability will refer to the cost-effectiveness of the CCS/CCUS systems, the capital investment (CAPEX), the operating cost (OPEX), the energy

consumption, and the main sources of revenue that include the price of carbon or utilization benefits [7]. Feasibility on the other hand is the practicality of the implementability of such systems and this incorporates technological readiness, infrastructure requirements, geographical boundaries like the source sink matching and institutions like regulatory frameworks and the acceptance of the same by the masses. Where economic viability is related to financial performance, the more general terms required to be implemented in the actual sense are referred to as feasibility.

Based on these definitions, this paper shall adopt a three dimensional analytical model which is inclusive of technological, economic and institutional insights (see Figure 1). The technology aspect focuses on the effectiveness and maturity of the system including the capture efficiency, energy usage and scalability in the diverse CCS paths. The economic factor evaluates cost structures, including both capital and operating costs, energy penalties and the effects of other non-rewarded costs like carbon charges and policy incentives. Institutional dimension evaluates regulatory and policy framework, including legal frameworks, mechanisms of liability, and social acceptance that affect the realization of CCS/CCUS projects.

This integrated framework (represented in Figure 1) suggests that the present study design is a case study approach to examine the representative CCS/CCUS projects within different industrial environments. They are all considered in the light of technological efficiency, economic viability, and institutional conditions, and a chance to comparatively assess their strengths and weaknesses is given. In doing this the study will identify the key drivers and constraints of CCS implementation, and evaluate the role of CCS in long-term low-carbon transition pathways.

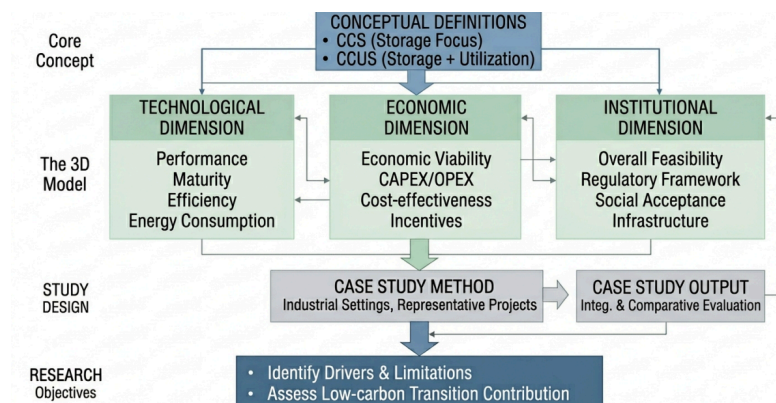


Figure 1. The three-dimensional analytical model for CCS/CCUS deployment

4. Case study: international comparative analysis of China and the international practices

4.1. Case study of China: Zhengning power plant CCS project

One of the first large-scale demonstration plants in China to capture carbon in coal-fired power generation is the Zhengning power plant, in Gansu Province. The project embraces the use of post-combustion capture technology, a technology that makes it possible to separate CO₂ and flue gases without necessarily changing the nature of the current combustion system [11].

Technologically, the CO₂ captured is pressurized and pumped through pipelines to close oil fields where it is used in oil recovery (EOR), with some being stored permanently underground. This combined utilization-storage model indicates a transitional model that will enhance the economic viability of CCS by generating revenue.

Economically, the project can be seen as having high initial investment especially in capture plants with the operation cost being highly sensitive to the price of energy since more energy is needed to run the capture and compression process. Without a properly established carbon pricing system, or consistent policy subsidies, the project is under a lot of pressure to become financially sustainable [11].

In terms of feasibility, technology is fairly mature, but its application is limited by geographical concerns, especially the necessity of efficient source-sink matching. The closeness to oil fields is one of the most important enabling factors of the operation of the project. Moreover, policy support and fiscal incentives are critical factors that determine its economic feasibility. On balance, the Zhengning project proves that CCS deployment is technically feasible in China, but also exposes structural issues, such as prohibitive investment costs and poor profitability. These results underscore the significance of policy guidance and technological optimization in the scale up of CCS applications.

4.2. International case: Sleipner CCS project in Norway

The Sleipner project in the North sea is generally considered the first commercial offshore project of CO₂ storage in the world, which has been operational since 1996. It is an innovative demonstration of massive scale CCS implementation with a stable regulatory framework [12]. The separation of CO₂ in natural gas production is captured, pressurized and introduced into deep saline aquifers under the seabed to be stored permanently. Sleipner is not based on utilization pathways, like EOR, as Zhengning project, but rather dedicated geological storage.

The project is economically advantaged due to the carbon tax policy in Norway that establishes a strong economic motivation towards mitigation of CO₂. Tax burden on emission effectively pays off the cost of capture and storage, and the project can be run in the long-term perspective. Consequently, Sleipner has proven to have a relatively stable and manageable unit costs of CO₂ storage, which can be used as a standard in CCS in the oil and gas industry.

Geologically, the project has very favorable geological parameters such as the presence of appropriate offshore saline formations, which guarantee the security of storage in the long term. In addition, good institutional backing, well-defined regulatory frameworks, and a long operational experience make it successful.

The Sleipner project represents a successful policy-based model of CCS, where economic incentives and regulatory predictability can be deployed on a long-term basis. Yet, its technological path is fixed to the particular geological conditions, and it cannot be directly duplicated in those areas that do not possess similar storage resources.

4.3. Comparative analysis

An analysis of the two cases shows that there are similarities and differences in the structure of deployment of CCS in the national context. Technologically, both projects use post-combustion capture, but are vastly different in their use pathways. The Zhengning project combines the use of CO₂ with EOR and partial storage, but in Sleipner, all uses offshore geological storage. These distinctions are indications of disparity in industrial settings and endowment of resources.

The Sleipner project has a developed carbon tax system in terms of economic performance, thus providing long-term financial sustainability. Conversely, the Zhengding project is under significant economic pressure since there is no overall carbon pricing system and is more reliant on government subsidies and policy support.

The conditions of space and resources also have a decisive role. The availability of appropriate offshore saline aquifers forms the basis of the success of Sleipner, and the availability of the oil fields contributes to the success of Zhengning in terms of the use and storage of CO₂. These are the geographical factors, which have a direct impact on the viability and size of CCS projects. The comparison of the institutions shows the difference in policy approaches. The Norwegian example focuses more on the carbon taxes and stable regulation in the long-term, compared to the Chinese example which employs more often demonstration projects organized by the government and fiscal support systems. In both instances, policy frameworks play a key role in facilitating the deployment of CCS.

All in all, the comparison indicates that viability of CCS is an outcome of complex interplay of technology maturity, economy and institutional factors. These three dimensions must be aligned to be effective in deployment and none of them would be adequate alone.

5. Conclusion

The paper is a comparative case study of the Zhengning project in China and the Sleipna project in Norway to present the role of carbon capture and storage (CCS) in the low-carbon transition pathway. The findings suggest that although CCS technology is technically viable and can be used to significantly cut down on the emissions of the industries that are hard to cut down, its mass implementation is conditional upon the alignment and regularity of the technological performance, economic viability and institutional backing.

First, the analysis has affirmed that CCS technology, especially the post-combustion capture technology has achieved a reasonably mature stage and can be implemented in many industrial sectors. Technological feasibility is however not enough to achieve successful deployment. Second, one of the constraints is economic factors. The challenge of CCS projects financial sustainability remains high due to high capital investment, operating costs and energy penalties. The comparative findings indicate that steadfast policy instruments, including the carbon price, are important to enhance economic feasibility. Third, institutional and geographical factors, in particular, source-sink matching and regulatory frameworks, are decisive factors in deciding on the viability and scalability of CCS.

Nevertheless, this discussion, relying on a few case studies, might not be quite representative of the variety of CCS applications in other regions and industries. Further studies might involve more detailed empirical investigations and the addition of more CCS projects that belong to various industries, which would contribute to the enhancement of the strength of comparative studies.

References

- [1] Sarkodie, S. A., Owusu, P. A., & Leirvik, T. (2020). Global effect of urban sprawl, industrialization, trade and economic development on carbon dioxide emissions. *Environmental Research Letters*, 15(3), 034049.
- [2] Van Soest, H. L., Den Elzen, M. G., & Van Vuuren, D. P. (2021). Net-zero emission targets for major emitting countries consistent with the Paris Agreement. *Nature Communications*, 12(1), 2140.
- [3] Liu, N., Liu, D., Zhan, Y., Chen, Q., Qiao, Y., & Tan, R. (2025). From innovation to integration: The evolving role of carbon capture and storage in global decarbonization. *cScience*, 1(1), e70008.
- [4] Van der Spek, M., Roussanaly, S., & Rubin, E. S. (2019). Best practices and recent advances in CCS cost engineering and economic analysis. *International Journal of Greenhouse Gas Control*, 83, 91-104.
- [5] Obi, D., Onyekuru, S., & Orga, A. (2025). Minimizing carbon capture costs in power plants: A novel dimensional analysis framework for techno-economic evaluation of oxyfuel combustion, pre-combustion, and post-combustion capture systems. *Energy Science & Engineering*, 13(4), 1749-1770.

- [6] Breyer, C., Fasihi, M., Bajamundi, C., & Creutzig, F. (2019). Direct air capture of CO₂: A key technology for ambitious climate change mitigation. *Joule*, 3(9), 2053-2057.
- [7] Prest, B. C., & Wingenroth, J. (2024). Operational versus capital expenditure risk in a clean energy transition. Washington (DC): Resources for the Future, 24-04.
- [8] Faber, G., Ruttinger, A., Strunge, T., Langhorst, T., Zimmermann, A., van der Hulst, M., ... & Tao, L. (2022). Adapting technology learning curves for prospective techno-economic and life cycle assessments of emerging carbon capture and utilization pathways. *Frontiers in Climate*, 4, 820261.
- [9] Vandeweyer, V., Candela, T., Lien, M., Koedel, U., Fechner, T., Bond, T., ... & Mellors, R. (2022, October). A technology readiness assessment for CCS site monitoring systems. In *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)* (pp. 23-24).
- [10] Tamaki, A. (2023). Applicability of the source–sink population concept to marine intertidal macro-invertebrates with planktonic larval stages. *Ecological Research*, 38(1), 4-41.
- [11] Ma, J., Wang, H., Li, L., Wang, Z., Chen, J., Cai, Z., ... & Zhang, X. (2024, October). Successes and lessons learned from development of CCS projects in Northern Shaanxi, China. In *Proceedings of the 17th Greenhouse Gas Control Technologies Conference (GHGT-17)* (pp. 20-24).
- [12] Singh, A. P., Maurya, S. P., Kant, R., Singh, K. H., Singh, R., Srivastava, M. K., ... & Verma, N. (2025). Implementing 4D seismic inversion based on linear programming techniques for CO₂ monitoring at the Sleipner field CCS site in the North Sea, Norway. *Acta Geophysica*, 73(1), 271-293.