Techno-Economic Analysis of State-of-the-Art Carbon Capture Technologies and Their Applications: Scient Metric Review

Subjects: Energy & Fuels
Contributor: Raghad Adam, Bertug Ozarisoy

Carbon dioxide (CO_2) emissions are a serious hazard to human life and the ecosystem. This is the reason that many measures have been put in place by the International Energy Agency (IEA) to reduce the anthropogenic-derived CO_2 concentration in the atmosphere. Today, the potential of renewable energy sources has led to an increased interest in investment in carbon capture and storage technologies worldwide. The aim of this paper is to investigate state-of-the-art carbon capture and storage (CCS) technologies and their derivations for the identification of effective methods during the implementation of evidence-based energy policies. To this extent, this study reviews the current methods in three concepts: post-combustion; pre-combustion; and oxy-fuel combustion processes. The objective of this study is to explore the knowledge gap in recent carbon capture methods and provide a comparison between the most influential methods with high potential to aid in carbon capture. The study presents the importance of using all available technologies during the post-combustion process. To accomplish this, an ontological approach was adopted to analyze the feasibility of the CCS technologies available on the market. The study findings demonstrate that priority should be given to the applicability of certain methods for both industrial and domestic applications. On the contrary, the study also suggests that using the post-combustion method has the greatest potential, whereas other studies recommend the efficiency of the oxy-fuel process. Furthermore, the study findings also highlight the importance of using life cycle assessment (LCA) methods for the implementation of carbon capture technologies in buildings. This study contributes to the energy policy design related to carbon capture technologies in buildings.

Keywords: adsorption ; carbon capture methods ; incineration ; oxy-fuel combustion ; post-combustion technologies

---

Climate change has been caused by a dramatic increase in greenhouse gases (GHG) [1]. This global problem has led to risks both to human health and the built environment worldwide. Warming climate conditions have caused coastal erosion and longer growing seasons in the agriculture industry. Additionally, a rise in global temperatures could result in melting glaciers and ice sheets and a rapid rise in sea levels. This phenomenon has caused changes in global weather and climate patterns. This is the reason that humankind has been experiencing more frequent floods, droughts, typhoons, and cyclones in the last three decades. In 2022, the Paris Agreement was put in place at the United Nations Climate Change Conference (COP21). This global summit was aimed at limiting global warming to below 2 °C, taking the baseline as pre-industrial temperature levels. This has led to efforts to limit the global temperature rise to 1.5 °C above pre-industrial levels [2]. To achieve this, the Paris Agreement requires all United Nations countries to set strict CO_2 emissions reduction targets, which are directly related to climate change and mitigation strategies.

In response to the findings of the IPCC's Special Report on Global Warming, the United Nations has called for an urgent plan to reduce CO_2 emissions and limit global temperatures to well below 1.5 °C [3]. To achieve this target, the IPCC report has recommended as a mandatory task for all UN countries to reduce CO_2 emissions by 2030 and reach the goals of 'net-zero' emissions by the mid-century. This would require a rapid behavioral change in consumers' habits of energy use [3]. This has also been put into effect for producing goods, planning effective land management, and avoiding deforestation. To achieve the IPCC's goals, increasing the use of renewable energy sources should be promoted, including solar and wind power systems, and the deployment of cost-effective emission technologies that aid in removing CO_2 emissions from the atmosphere.

In 2018, the summary for policymakers of the IPCC Special Report indicated that MAGICC and FAIR models are correlated with geophysical data gathered from simulations. The study found that there is a high degree of variation within a specific category and between the models [4]. To this extent, many forecasting scenarios propose a temporary increase in global temperatures. This finding has been noted in previous studies on stringent mitigation efforts to reduce CO_2 emissions. Many scientists found that there is a very limited methodological framework, which has been considered the database approach to keeping future global warming below 1.5 °C throughout the 21st century [5]. However, most studies highlighted that there is an inconsistent pathway in the global databases in order to limit the global temperature rise to 1.5 °C [6][7]. This set threshold limit is expected to reach the benchmark criteria around the mid-century before lowering global temperatures to below pre-industrial records by 2100 [8]. However, it is difficult to distinguish the exact temperature characteristics of the different pathway categories due to various uncertainties and model dependencies in the simulation models. The extant literature studies stress that there is a possibility of reaching the exceedance limit of the average rise of 1.5 °C in global temperature by the mid-century because of the lack of data available on the assessment of the reliability of the weather data time series [9].

In accordance with the Paris Agreement and the POST-2020 framework, numerous nations have come to a consensus to tackle the pressing issue of global warming and its adverse environmental consequences. To mitigate the risks posed by climate change, these countries have established distinct objectives aimed at reducing greenhouse gas emissions. As an illustration, the European Union (EU) has committed to reducing its CO_2 emissions by 40% by the year 2030. Simultaneously, the United States (US) has set its target for a reduction of 26–28% by the year 2025. A comprehensive breakdown of these targets can be found in **Table 1**.

Table 1. Representative countries' CO_2 emissions reduction targets.

Country	CO_2 Emissions Reduction Target	Target Year
The EU	**40%**	**2030**
The USA	**26–28%**	**2025**
China	**60–65%**	**2030**
South Korea	**37%**	**2030**
Japan	**26%**	**2030**
Malaysia	**45%**	**2030**

Data source [10].

These targets represent significant efforts on the part of the international community to combat climate change and preserve our planet's delicate ecological balance. By actively pursuing these goals, nations are taking crucial steps towards a more sustainable and environmentally conscious future [10]. This study aims to address several gaps in the literature related to carbon capture and sequestration (CCS) in order to outline a state-of-the-art techno-economic analysis in the building sector. The study also seeks to provide an in-depth overview of the current technologies that could help mitigate climate change impacts by 2030 in line with the Paris Agreement regulations. Having reviewed recent research articles published in this research area, the main objective of this present study is to research modern carbon capture and storage technologies and evaluate their technological specifications as well as their economic feasibility.

This study also aims to answer the question of whether CCS has the potential to mitigate CO_2 emissions as well as climate change effects in the built environment. To this extent, the significance of post- and oxy-fuel combustions is explored to determine a reliable assessment both in industrial and domestic applications. The novelty of the present study is to develop a cost-effective assessment criterion for CCS technologies by adopting a universal design approach in any type of building application, as shown in **Figure 1**. One of the main contributions to the knowledge is to develop economically viable CCS technologies to lower global temperatures and remove CO_2 concentrations from the atmosphere.

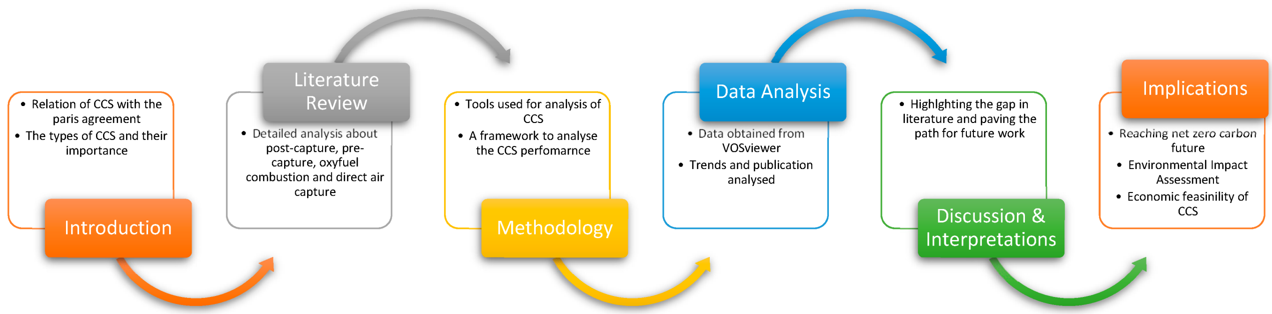

Figure 1. Conceptualization framework of the present study. Drawn by author.

The intention of the present study is to analyze the characteristics of oxy-fuel combustion to develop an effective optimization model for use in power generation plants. To accomplish this, a comprehensive methodological framework is produced to outline the policy design implications. The life cycle cost assessment approach was also explored to validate the adopted optimization models. Additionally, the findings were supported using the meta-analysis approach to gather research outputs from a systematic literature review. Policy design implications were outlined to demonstrate a roadmap for using carbon capture technologies and their applications. The systematic literature review presents a keyword analysis to determine a new method of design for the cost-effectiveness of carbon capture technologies. To fill the knowledge gap, a comprehensive research methodology framework was also outlined. A bibliometric review of all available methods was presented. Furthermore, the extant literature review analysis of state-of-the-art CCS technologies was investigated globally.

This paper set out to execute the state-of-the-art methodological framework considering the significance of CCS technologies in building design applications. The brief historical background is presented in Section 2. To this extent, the systematic literature review was undertaken by gathering original research papers, review articles, and policy documents worldwide. The conceptual framework is outlined to demonstrate the cost-effectiveness of implementing CCS technologies. Meta-analysis findings are presented in Section 4. The discussion is delineated to provide the applicability of three methods, namely, post-, pre-, and oxy-fuel combustion processes in Section 5. Conclusions are drawn to demonstrate the significance of the research outputs in Section 6.

References

1. Chen, X.; Wu, X. The roles of carbon capture, utilization and storage in the transition to a low-carbon energy system using a stochastic optimal scheduling approach. J. Clean. Prod. 2022, 366, 132860.
2. Gowd, S.C.; Ganeshan, P.; Vigneswaran, V.S.; Hossain, M.S.; Kumar, D.; Rajendran, K.; Ngo, H.H.; Pugazhendhi, A. Economic perspectives and policy insights on carbon capture, storage, and utilization for sustainable development. Sci. Total. Environ. 2023, 883, 163656.
3. Henry, A.; McCallum, C.; McStay, D.; Rooney, D.; Robertson, P.; Foley, A. Analysis of wind to hydrogen production and carbon capture utilisation and storage systems for novel production of chemical energy carriers. J. Clean. Prod. 2022, 354, 131695.
4. Kim, Y.J.; Cho, S.H.; Sharma, B.P. Constructing efficient portfolios of low-carbon technologies. Renew. Sustain. Energy Rev. 2021, 150, 111515.
5. Masson-Delmotte, V.; Zhai, P.; Pörtner, H.-O.; Roberts, D.; Skea, J.; Shukla, P.R.; Pirani, A.; Moufouma-Okia, W.; Péan, C.; Pidcock, R.; et al. Global Warming of 1.5 °C an IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty Edited by Science Officer Science Assistant Graphics Officer Working Group I Technical Support Unit. 2019. Available online: www.environmentalgraphiti.org (accessed on 16 November 2022).
6. D'Amore, F.; Romano, M.C.; Bezzo, F. Carbon capture and storage from energy and industrial emission sources: A Europe-wide supply chain optimisation. J. Clean. Prod. 2021, 290, 125202.
7. Olabi, A.G.; Obaideen, K.; Elsaid, K.; Wilberforce, T.; Sayed, E.T.; Maghrabie, H.M.; Abdelkareem, M.A. Assessment of the pre-combustion carbon capture contribution into sustainable development goals SDGs using novel indicators. Renew. Sustain. Energy Rev. 2022, 153, 111710.
8. Du, K.; Li, P.; Yan, Z. Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. Technol. Forecast. Soc. Chang. 2019, 146, 297–303.
9. Giannousakis, A.; Hilaire, J.; Nemet, G.F.; Luderer, G.; Pietzcker, R.C.; Rodrigues, R.; Baumstark, L.; Kriegler, E. How uncertainty in technology costs and carbon dioxide removal availability affect climate mitigation pathways. Energy 2021, 216, 119253.
10. Heubaum, H.; Biermann, F. Integrating global energy and climate governance: The changing role of the International Energy Agency. Energy Policy 2015, 87, 229–239.