A Review of Achieving Carbon Neutrality and Peak Carbon Emissions in Aspects of Energy Technology Developments, Ecological Approaches, and Economic and Political Assistances

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Abstract. Carbon neutrality and peak carbon dioxide emission targets are crucial in curbing climate change by reducing greenhouse gas (GHG) emissions and limiting the extent of global temperature rise. They are called "dual carbon targets" together. Carbon neutrality aims to stabilize atmospheric CO_2 concentration, and the peak carbon dioxide emissions target sets a clear goal for when CO_2 emissions must start decreasing to avoid the most severe impacts of climate change. This article will illustrate the situation of dual carbon targets, how to achieve the targets in approaches of technology, ecology, and economic and political supports, and lastly, the challenges that would be faced in the "post-carbon-neutrality era."

Keywords: Carbon neutrality, peak carbon dioxide emissions, global warming.

1 Introduction

Given its status as Earth's predominant and pivotal elemental cycle, the carbon cycle is paramount in fostering a sustainable and environmentally conscious society[1, 2]. Amidst the ongoing process of urbanization and industrialization, terrestrial carbon dioxide (CO_2) emissions escalate, exacerbating the challenges posed by global climate change and the associated rise in sea levels[3]. According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), the concentration of CO_2 has increased from 285 ppm to 414 ppm from 1850 to 2020, and global average temperature had increased by 1.5°C[4]. In 2023, there was a 1.1% rise in global-related CO_2 emissions, resulting in an additional 410 million tons, marking a new record high of 37.4 billion tons[5]. The temperature increment was attributed to the consumption of fossil fuels and deforestation, which led to the accumulation of greenhouse gases (GHG) like CO_2 in atmosphere. To mitigate the rate of global warming attributed to greenhouse gasses (GHG), the Sustainable Development Goals (SDGs) and the Paris Climate Agreement established a global initiative. However, a significant proportion of nations continue to grapple with attaining the prescribed carbon neutrality, which entails the realization of a sustainable, low-carbon economy characterized by minimal CO_2 emissions[6]. In that case, the

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concept of Carbon Neutrality and Peak Carbon Dioxide Emissions has been carried out in recent years[7].

"Carbon Neutrality" refers to achieving a balance between carbon emissions by fossil fuels and territory changes, as well as the carbon captured by land and ocean ecosystems through absorption and technological approaches, that is, with a net emission of CO_2 is zero, as illustrated in Equation (1). Carbon capture, utilization, and storage (CCUS) is usually achieved using physical, chemical, and biological technologies. At present, there are significant difficulties in implementing industrial-scale practical applications, and it would not be primary method for carbon sequestration in the near future[8].

$$E_{net} = E_{human} - (C_{land} + C_{ocean} - CCUS) \tag{1}$$

Where:

E_{net} – Net emissions of CO_2, [Mt C_{eq}/annual].
E_{human} – CO_2 emissions by human activities, [Mt C_{eq}/annual].
C_{land} – Carbon captured by land, [Mt C_{eq}/annual].
C_{ocean} – Carbon captured by ocean, [Mt C_{eq}/annual].
$CCUS$ – Carbon secured by Captured, Utilization, and Storage, [Mt C_{eq}/annual].

"Peak Carbon Dioxide Emissions" means that CO_2 emissions by fossil fuel consumption have reached to the top, and future CO_2 emissions by fossil fuels will not be higher than that peak point. The European Union (EU) had achieved the CO_2 peak point by the 1980s, and the United States (US) had reached it by 2005[9]. The anthropogenic CO_2 emissions by one of the top three economies, China, has been through a stable phase (around 2.7 billion tons of carbon annually), and it can be estimated that China will achieve the peak CO_2 emission goal by the end of 2030[10].

This article undertakes a comprehensive analysis of the possibilities of "dual carbon target" from aspects of technology developments, ecosphere, and politics. Based on this analysis, the article presents reasoned conclusions and recommendations for the path to carbon neutrality and the post-carbon-neutrality era.

2 Aspects Achieving Carbon Neutrality

2.1 Technology Developments

Technology developments play significant roles in achieving carbon neutrality. According to Equation (1), they can reduce anthropogenic CO_2 emissions and increase the amounts of CCUS. There are three typical technologies that have the most extraordinary potencies for "dual carbon targets".

Hydrogen Technology. The widespread applications of hydrogen as a raw material in industry, direct combustion for energy supply, and hydrogen fuel cell vehicles (HFCVs) are the main directions of hydrogen technologies, and those technologies have made great progress in recent years[11]. Global hydrogen consumption has reached 95 million tons in 2022, and almost 95% of hydrogen was produced from fossil fuels and industrial by-products[12]. However, hydrogen production can achieve its maximum potential by utilizing renewable energy to electrolyze water, since water electrolysers can meet the requirements of zero emission of CO_2, and such hydrogen is called green hydrogen. Alkaline, Proton Exchange Membrane (PEM), and solid oxide water electrolysers are popular technologies at present, and their advantages and drawbacks are shown in Table 1[13].

Table 1. Comparison of water electrolysis technologies[13].

Electrolysers	Advantages	Disadvantages
PEM	High current density Not toxic and corrosive High fuel cell efficiency High gas purity Small size, easy to integrate Operational temperature is ~80°C	High cost Noble metal catalysts required
Alkaline	Low cost Noble metal catalysts not required	Low current density Low gas purity Corrosive and toxic V_2O_5 existed Bulky, difficult to integrate
Solid Oxide	Low energy consumption Noble metal catalysts not required	Ceramics utilized, difficult to process the components High cost Operational temperature is 600-900°C

Carbon Capture and Storage (CCS). The main focus in climate change mitigation policy has been the emergence of CCS, aiming to curtail emissions from industrial activities and fossil fuel-based energy generation. The implementation of CCS is regarded as instrumental in constraining global warming to the ambitious target of 1.5°C[4]. Thus, CCS performs a significant role in carbon neutrality. There are many selections for carbon sequestration, as illustrated in Figure 1[14].

Figure 2[15] illustrates a typical commercial example of exploring ocean storage's viability in Captain Sandstone, Scotland. The Captain Sandstone is situated within the confines of the Moray Firth, resting at a depth of approximately half a mile beneath the seabed. It is positioned approximately 30 miles within the North Sea. CO_2 was captured at the power plant, and then transferred to either storage or oil recovery. Subsequently, CO_2 was injected into a saline aquifer at a rig. On the other side, CO_2 was compressed and delivered to the oil field underground after the Enhanced Oil Recovery (EOR). Lastly, oil holds the potential for collection and transportation for alternate usages. EOR encompasses various techniques to augment oil retrieval beyond conventional methodologies, involving a decrease in oil saturation below the residual oil saturation. The recovery of oils trapped due to capillary forces, particularly following a water flood in light oil reservoirs, as well as oils exhibiting immobility or near-immobility because of high viscosity, such as heavy oil and tar sands, necessitates reducing the oil saturation below residual oil saturation. Methods such as miscible processes, chemical floods, and steam-based techniques prove efficacious in diminishing residual oil saturation, thereby qualifying as EOR methods[16].

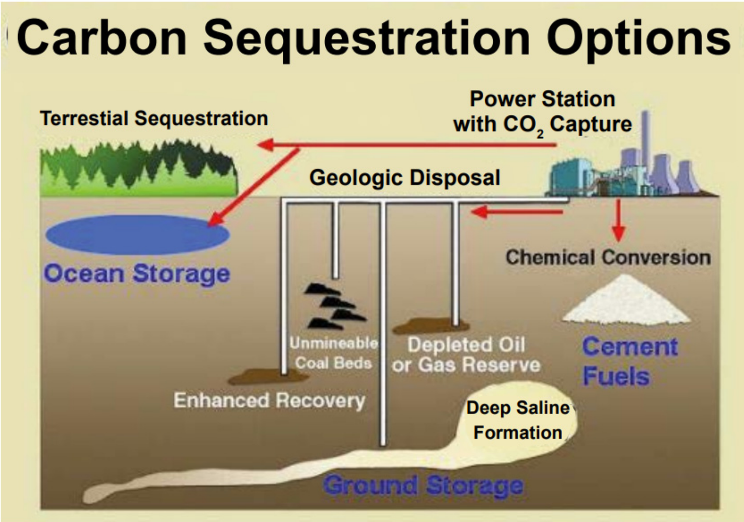

Fig. 1. Carbon sequestration options[14].

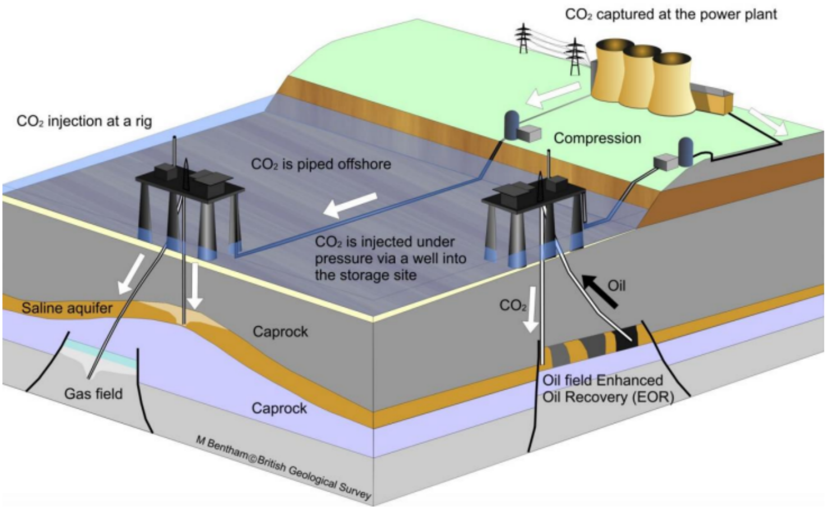

Fig. 2. CCS infrastructure entails geological formations[15].

A site suitable for CO_2 storage necessitates ample storage capacity, injectivity, a robust confining unit or impermeable caprock, and a geologically stable environment to safeguard against potential compromise to the site's integrity. CO_2 sequestration, as demonstrated in Figure 2, can be conducted in three aspects. The first point pertains to the utilization of both active and depleted oil and gas fields for the purpose of oil and gas extraction, particularly for conducting EOR. The next aspect has to do with deep un-mineable coal layers proficient to enhancing methane recovery named Enhanced coalbed methane (ECBM) recovery. The final aspect concerns deep saline aquifers, which have historically been utilized for cost-effective oil and gas storage and holding the potential for adaption to CO_2 storage techniques[17]. Another typical approach for carbon sequestration and storage is underground storage. CO_2 was captured and injected into underground reservoir around 1100m depth with approximately a caprock of 150m thick, as shown in Figure 3[14].

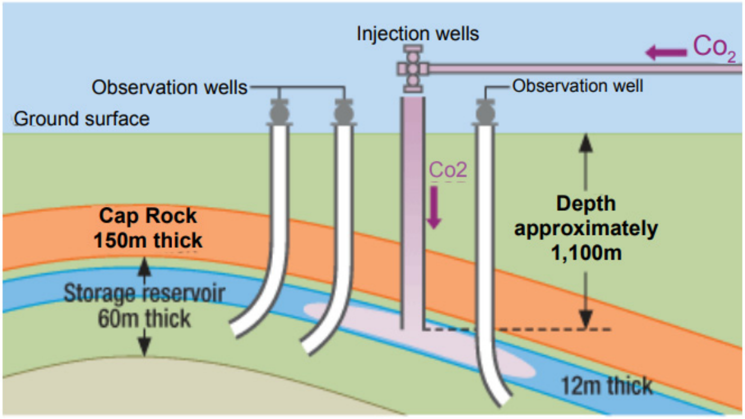

Fig. 3. Cross-sectional Diagram of Underground CO_2 Storage[14].

2.2 Ecology

It is imperative to focus on ecological conservation, construction, and management to enhance carbon sinks. Using photosynthesis and carbon cycle processes, terrestrial and marine systems sequester CO_2 from the atmosphere, transforming it into a significant reservoir of atmospheric CO_2 known as the "ecosystem carbon sink." Typically, three primary destinations or sinks (reservoirs) exist for CO_2 emissions from fossil fuels and land use, as illustrated in Figure 4[9]. From a global scale, approximately 46% of anthropogenic CO_2 emissions remained in the atmosphere, followed by 31% of them was absorbed and fixed by terrestrial ecosystems. Moreover, 23% of CO_2 emissions was sequestered by marine ecosystem, or called "ocean carbon sink"[9]. It is worth noting that land use change in Figure 4 represented by tropical deforestation resulted to around 1.6 billion tons of CO_2 per year was released to atmosphere. Furthermore, given that the majority of the world's ocean resources are considered global public resources, it is arguably imperative that all nations are granted equal access to the carbon sink capability[18].

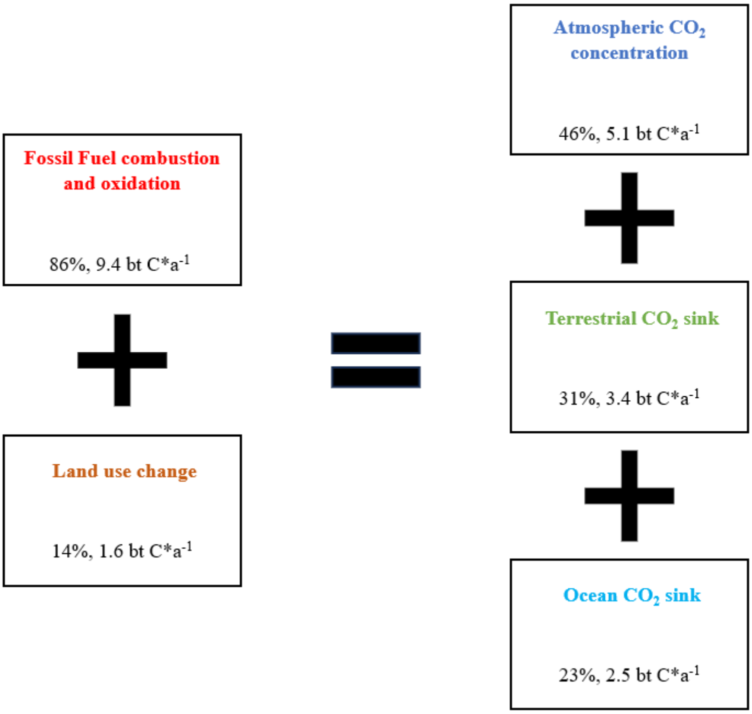

Fig. 4. Global anthropogenic CO_2 emissions and their fates annually during 2010-2019[8,9].

To optimize the carbon sequestration potential of ecosystems, a comprehensive approach to ecological construction and management is required. This approach must be rooted in three fundamental principles: 1) the restoration and preservation of natural vegetation cover, 2) the mitigation of land-use changes impacts, and 3) the promotion of sustainable land management practices[8]. By adhering to these principles, ecosystems function optimally as carbon sinks, thereby contributing to the global effort to mitigate climate change.

2.3 Economy and Political Support

Following a decline of approximately 4.5% in 2023, CO_2 emissions in advanced economies had fallen below the levels recorded in 1973, as depicted in Figure 5[5]. While CO_2 emissions withing this group of countries reached comparable nadirs in 2020, 1974-75, and 1982-83, two notable deviations emerged. Firstly, unlike the transient downturns observed in 1974-75 and 1982-83, CO_2 emissions from advanced economies have been experiencing a structural decline since 2007. Moreover, the advanced economy Gross Domestic Product (GDP) experienced a growth of around 1.7% in 2023, in comparison of stagnation or outright recession in the periods mentioned earlier. Consequently, the shrinkage in 2023 indicated the most significant percentage drop in advanced economy emissions during the recessionary period[5].

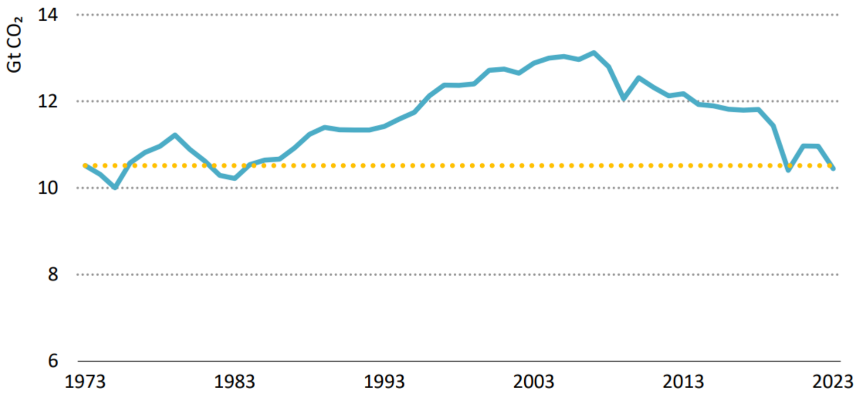

Fig. 5. CO2 emissions from combustion in advanced economies, 1973-2023[5].

In such environment, several policies that improve developments of Carbon Neutrality and Peak Carbon Dioxide Emission Target were promulgated in leading economies. China released Technology Supporting Peak Carbon Dioxide Emissions and Carbon Neutrality Implementation Plan (2022-2030) in 2022[19]. The policy stated that to consolidate the measures to support the realization of the achieve Carbon Dual Targets in 2060, a three-fold approach will be utilized to execute this plan. The very first was reinforcing institutional guarantees by establishing an interministerial coordination mechanism for dual-carbon science and technology innovation, as well as a national carbon dual targets committee. Secondly, strengthening the tracking and monitoring of carbon neutrality technologies, focusing on the investment in R&D and applications, and promoting technology iterations through science and technology assessments and evaluations. Lastly, bolstering the establishment of low-carbon technology infringement information records in the national public credit-sharing platform[19].

Another example was the United States. Similarly to China, the US has implemented measures aimed at achieving carbon neutrality and undertaken legislative reformations at both federal and state levels: 1) The presidency has established several targets, including reducing CO_2 emissions by 50% to 52% with respect to 2005 levels by 2030. Additionally, aims have been set for achieving a carbon-free power sector by 2035, and attaining carbon emissions for the entire economy by 2050[20]. 2) As of April in 2023, a total of 22 states, along with Washington D. C. and Puerto Rico, had established political or executive targets for promoting clean power production[21]. 3) The target of achieving net-zero emissions for all light vehicles has been set for 2035, with the additional mandate that federal government procurement of such vehicles will be ceased by 2027[22].

3 Challenges and Recommendation

It is crucial to consider the potential challenges and barriers that humanity may encounter after attaining dual carbon targets. This contemplation is vital to guarantee a seamless and efficient transition to the "post carbon neutrality" era: In the absence of CO_2

emissions or as atmospheric CO_2 concentration decreases, several changes may occur in natural and social systems. One conceivable scenario is a reduction in atmospheric CO_2 concentration, potentially leading to global cooling, drought, and a decrease in land fertility, which could lead to reduced grain production and other relative issues[8]. Consequently, the anticipated values of land and ocean carbon sink as described previously should err on the side of caution. Furthermore, achieving carbon neutrality requires a comprehensive and intricate effort that impacts all aspects of society and has lasting consequences. Besides, carbon sink augmentation was also a complicated problem. Reckless and unscientific practices must be avoided by obtaining a deeper understanding of where humankind is positioned in the ecosphere, afforestation, for instance, in arid areas that are not suitable for tree planting, and other practices that violate scientific laws must be abandoned. Such activities, if not grounded in scientific principles, can lead to ecosystem damage or even collapse. Hence, adherence to scientific laws and careful planning is paramount in the pursuit of carbon neutrality[8].

4 Conclusion

The primary objective of Carbon Neutrality is to address the issue of global warming. There is vast expense in developing energy and CCUS technology in order to meet net zero emissions, and there is still a long way to ultimately achieve this goal in reality. From an ecological point of view, a huge problem is the increase in carbon sinks in ocean and land usage. Last but not least, most nations have made an example and promulgated laws and policies that could bolster the development of a carbon neutrality society, and the more efforts are needed, the more guarantees will be provided to the people working on dual carbon targets. With the combination of technological developments, ecological efforts, and political and economic assistance, the Carbon Neutrality and Peak Carbon Dioxide Emission targets will be achieved in the near future.

References

1. Olah G. et al. Anthropogenic chemical carbon cycle for a sustainable future. J Am Chem Soc, 12881-12898, 2021.
2. Xu Y. et al. Structures of urban carbon cycle based on network indicators: Cases of typical cities in China. J Clean Prod 282, 125405, 2021.
3. Hansen J. et al. Climate sensitivity, sea level and atmospheric carbon dioxide. Phil Trans R Soc A 371, 20120294, 2013.
4. IPCC, Climate Change 2022: Mitigation of Climate Change. IPCC; 2022.
5. International Energy Agency. CO_2 Emissions in 2023. IEA, 2024.
6. Shao X et al. Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. J Environ Manage 296, 113189, 2021.
7. Rogelj J et al. A new scenario logic for the Paris Agreement long-term temperature goal. Nature, 573, 357-363, 2019.
8. Fang JY. Ecological perspective of carbon neutrality. Chinese J Plant Eco 45(11), 1173-1176, 2021 [in Chinese].

9. Friedlingstein P et al. Global carbon budget 2020. Earth System Science Data, 12, 3269-3340, 2020.
10. Shi C. et al. How can China achieve the 2030 carbon peak goal – a crossover analysis based on low-carbon economics and deep learning. Energy, 269, 126776, 2023.
11. Cai L. et al. The advantages and development of hydrogen energy technology. China New Technologies and Products, (3), 175, 2015 [in Chinese].
12. International Energy Agency. Global Hydrogen Review. IEA 2023.
13. Lei C., Li D. Key technologies and development status of hydrogen energy utilization under the background of carbon neutrality. Power Generation Technology, 42(2), 207-217, 2021 [in Chinese].
14. Shahbazi A, Nasab BR. Carbon Capture and Storage (CCS) and its impacts on climate change and global warming. J Pet Environ Biotechnol 7, 291, 2016.
15. Bui A. The feasibility of implementing carbon capture and storage at Yale. A Senior Thesis presented to the faculty of the Department of Geology and Geophysics, Yale University, 2017.
16. Sara T., Enhanced Oil Recovery – An Overview. Oil & Gas Sci and Technol, 63, 9-19, 2008.
17. Fan N. et al. Numerical study on enhancing coalbed methane recovery by injecting N_2/CO_2 mixtures and its geological significance. Energy Science & Engineering, 8(4), 1104-1119, 2020.
18. Fang JY et al. Carbon emissions from China and the World. Science Press. 240, 2018 [in Chinese].
19. Central People's Government of People' Republic of China. Policy Interpretation of "Technology Supported Peak Carbon Dioxide Emissions and Carbon Neutrality Implementation Plan (2022-2030)". Central People's Government of People's Republic of China, 2022 [in Chinese].
20. The White House. FACT SHEET: President Biden to Catalyze Global Climate Action through the Major Economies Forum on Energy and Climate. The White House, 2023.
21. Clean Energy States Alliance. Table of 100% Clean Energy States. CESA, 2023.
22. Federal Government of the United States. Executive Order 14057. Federal Government of the United States, 2018.