## Summary

The urgent need to mitigate climate change has led to growing interest in Carbon Dioxide Removal (CDR) technologies, particularly those involving geological storage of $CO_2$. These include methods like Biomass with Carbon Capture and Storage (BioCCS) and Direct Air Carbon Capture and Storage (DACCS), which are increasingly seen as necessary to complement efforts to reduce greenhouse gas (GHG) emissions. Both the Intergovernmental Panel on Climate Change (IPCC) and German studies agree that Carbon Dioxide Removal will be critical to achieve climate neutrality, particularly in the second half of this century. However, the extent of its use is closely tied to the pace and scale of current mitigation efforts. If emission reductions are delayed, greater reliance on CDR technologies will be necessary.

Geological storage of $CO_2$ has gained renewed attention, though it has faced controversy. Earlier discussions about extending the life of fossil fuel power plants using $CO_2$ storage have faded, but the need for storage as offset for residual and negative emissions is reemerging. Current projections indicate that by 2030, the European Union aims to store 50 million tons of $CO_2$, with future demand likely to increase significantly by 2040 and beyond. However, the use of CDR technologies raises critical questions about their technical feasibility, economic viability, environmental sustainability, and societal acceptance.

The focus of this study is on the risks and opportunities associated with the geological storage of $CO_2$, with a specific emphasis on offshore storage. While technologies for $CO_2$ capture and nature-based removals are not the focus here, the study assesses the governance structures needed to minimize risks and improve the safety and sustainability of geological carbon storage. Key risks include operational irregularities during $CO_2$ injection, environmental impacts on marine ecosystems, and challenges related to public perception and financial incentives. Deterring emission reductions is an important – perhaps the most important – political risk in this context. If this risk is not addressed, for example by separating targets and policies for mitigation, nature-based removals and long-term geological storage, it may be difficult to gain acceptance and public support for geological carbon storage.

1. **Regulatory and technical framework**: The EU's Carbon Capture and Storage (CCS) Directive offers a foundation for managing $CO_2$ storage, but there is room for improvement. Independent third-party oversight harmonized $CO_2$ purity standards, and confidential reporting of irregularities are recommended to enhance transparency and public trust. A lack of regulatory standardization across EU Member States leads to inefficiencies and higher operational costs, creating unnecessary risks for project operators.

2. **Operational challenges**: Past offshore $CO_2$ storage projects, such as those at Sleipner and Snøhvit, have experienced operational irregularities during the injection of $CO_2$, leading to significant cost overruns. These experiences highlight the importance of proper site selection and injection protocols to mitigate risks. The reuse of existing infrastructure, such as pipelines from the fossil fuel industry, may seem cost-effective but often introduces additional risks due to technical incompatibility with $CO_2$ storage requirements.

3. **Environmental and human safety**: While offshore $CO_2$ storage is associated with relatively low environmental risks, they cannot be ignored. Marine ecosystems may be impacted by potential $CO_2$ leakage, noise pollution from increased marine traffic, and other indirect effects. For human populations, the risk of exposure to $CO_2$ leakage is low, but it is prudent to avoid storage sites near urban areas. continuous and comprehensive monitoring is necessary to detect and mitigate any irregularities during storage operations.

4. **Monitoring and long-term liability**: Effective governance requires continuous monitoring of storage sites, both during the injection phase and long after closure. Independent third-party monitors should be involved in site selection, permitting, and ongoing assessments. Long-term liability frameworks must be clear, ensuring that financial provisions are in place to cover remediation and maintenance costs post-closure. EU guidelines currently require a 20- to 40-year post-closure monitoring period, after which state authorities assume responsibility, provided that the $CO_2$ storage has been deemed secure.

To ensure that the deployment of geological carbon storage is both safe and environmentally sustainable, several governance enhancements are recommended:

- **Standardized $CO_2$ purity rules**: Establishing a set of common standards for $CO_2$ purity across the EU would reduce regulatory uncertainties, lower operational costs, and foster cross-border collaboration. This would create a level playing field for operators and improve the overall efficiency and safety of carbon storage projects.
- **Independent monitoring**: Independent third-party verifiers, appointed by competent authorities, should oversee the monitoring of storage sites. These verifiers would increase transparency and build public confidence in the safety of carbon storage projects. Real-time monitoring systems and robust mechanisms to report and address irregularities are essential to mitigate risks.
- **Expanded environmental assessments**: Environmental impact assessments for $CO_2$ storage projects should be expanded to include indirect effects such as noise pollution and increased vessel traffic at offshore storage sites. Continuous monitoring of these effects should be part of the governance framework to minimize any unintended environmental consequences.
- **Integrated spatial planning**: Comprehensive spatial planning is essential to avoid conflicts with other land uses, especially in environmentally sensitive areas. For example, defining no-go zones in marine protection areas could help minimize environmental risks. Proper site selection and injection practices are crucial to ensuring the long-term success of $CO_2$ storage projects.
- **Post-closure financial liability**: Operators must be required to set aside sufficient financial provisions to cover post-closure costs, including potential remediation efforts. The European Commission's guidance on financial security is a step in the right direction, but it should be regularly reviewed to ensure that financial requirements keep pace with the evolving risks and costs of $CO_2$ storage.
- **Government involvement**: Increased government involvement in $CO_2$ storage projects can help address societal concerns and improve public trust. Governments can also play a key role in managing demand for $CO_2$ storage capacity and ensuring that storage projects align with national and regional climate goals.
- **Policy evolution:** Policymakers must remain flexible and responsive to new risks and opportunities as $CO_2$ storage technologies mature. Regularly reviewing and updating governance frameworks will ensure that emerging risks, such as those associated with transboundary transport and storage in environmentally sensitive areas, are appropriately managed.

While reducing GHG emissions across all sectors remains the top priority for achieving climate neutrality, geological carbon storage can play a critical role in offsetting residual emissions and achieving negative emissions, particularly in the second half of this century. By implementing the governance improvements recommended in this study, policymakers can ensure that carbon storage in geological formations is safe, sustainable, and capable of contributing to the broader goal of maintaining long-term climate neutrality. These measures will help build public trust, ensure environmental safety, and align carbon storage efforts with broader decarbonization strategies.