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(Review Article)

Future directions in geological research impacting renewable energy and carbon capture: A synthesis of sustainable management techniques

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Abstract

Geological research plays a pivotal role in shaping the future of renewable energy and carbon capture initiatives, offering insights into sustainable management techniques. This review synthesizes the future directions in geological research that impact renewable energy and carbon capture, focusing on sustainable management techniques. Future geological research will increasingly focus on enhancing the integration of renewable energy sources into existing energy systems. This includes the development of innovative geological mapping techniques to identify and characterize renewable energy resources with greater precision, aiding in the selection of optimal sites for energy production. Additionally, there will be a growing emphasis on utilizing geological data to assess the feasibility of carbon capture and storage (CCS) projects, particularly in volcanic regions, where the unique geological characteristics offer potential for efficient carbon sequestration. Another key aspect of future geological research is the advancement of monitoring and modeling techniques to evaluate the long-term performance and environmental impact of renewable energy and CCS projects. This includes the use of advanced geophysical and geochemical methods to monitor subsurface changes associated with energy extraction and carbon storage, ensuring the effectiveness and safety of these practices. Furthermore, future research will explore the potential of geological formations, such as deep saline aquifers and depleted oil and gas reservoirs, for large-scale carbon storage. This will involve developing strategies to enhance storage capacity and mitigate the risk of CO_2 leakage, contributing to the sustainable management of carbon emissions. In conclusion, future geological research will play a critical role in advancing renewable energy and carbon capture technologies, offering sustainable management techniques that are essential for addressing climate change. By focusing on innovative mapping, monitoring, and modeling approaches, researchers can pave the way for a more sustainable energy future.

Keywords: Future Directions; Geological Research; Renewable Energy; Carbon Capture; Sustainable Management Techniques

1. Introduction

Geological research plays a pivotal role in the development and management of renewable energy sources and carbon capture initiatives (Hou, et. al., 2022, Wei, et. al., 2021). As the world transitions towards cleaner and more sustainable energy sources, understanding the geological aspects of these technologies becomes increasingly important. This introduction provides an overview of the significance of geological research in renewable energy and carbon capture, highlights future directions in geological research, and sets the stage for exploring the synthesis of sustainable management techniques in these areas (Fanchi, 2023, Hassan, et. al., 2024).

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Renewable energy sources, such as wind, solar, and geothermal energy, are critical components of global efforts to reduce greenhouse gas emissions and mitigate climate change (Adelani, et. al., 2024, Udegbe, et. al., 2024). Geological research is essential for identifying suitable locations for renewable energy projects, assessing resource potential, and optimizing energy production. Additionally, geological studies are crucial for carbon capture and storage (CCS) projects, which aim to capture carbon dioxide emissions from industrial processes and power generation and store them underground to prevent their release into the atmosphere (Ma, et. al., 2022, Yang, et. al., 2023).

Future directions in geological research are likely to focus on innovative mapping techniques for renewable energy resources, feasibility assessments of carbon storage in geological formations, and advanced monitoring and modeling techniques for renewable energy and CCS projects (Adelani, et. al., 2024, Oyewole, et. al., 2024). These advancements will enable more accurate site selection, improve the efficiency of energy production, and enhance the safety and effectiveness of carbon storage.

This paper will explore the future directions of geological research in renewable energy and carbon capture, with a focus on synthesizing sustainable management techniques. By examining the latest developments and trends in geological research, we can gain valuable insights into how best to harness renewable energy sources and effectively manage carbon capture projects to mitigate climate change and ensure a sustainable future.

Geological research is at the forefront of shaping the future of renewable energy and carbon capture technologies, playing a crucial role in advancing sustainable management practices (Addy, et. al., 2024, Penerbit, 2020). As the global demand for clean energy grows and the urgency to combat climate change intensifies, it is essential to explore the potential of geological research to drive innovation and enhance the sustainability of these critical sectors.

The importance of geological research in renewable energy and carbon capture cannot be overstated. Geological studies provide valuable insights into the Earth's subsurface, helping identify optimal locations for renewable energy projects and assess the feasibility of carbon capture and storage solutions (Albertz, Stewart & Goteti, 2023, Yao, et. al., 2023). By understanding the geological characteristics of different regions, researchers can determine the viability of various energy sources and develop strategies to mitigate environmental impacts.

Looking ahead, future directions in geological research are poised to revolutionize the way we approach renewable energy and carbon capture (Oyegoke, et. al., 2020, Udegbe, et. al., 2024). Advances in technology, such as remote sensing and geophysical imaging, offer new opportunities to explore and exploit renewable energy resources. Additionally, innovative approaches to carbon capture and storage, such as mineralization and enhanced oil recovery, are being developed to make carbon capture more efficient and cost-effective.

This paper will delve into the cutting-edge developments in geological research that are shaping the future of renewable energy and carbon capture. By examining the latest trends and innovations in the field, we aim to provide insights into how geological research can be leveraged to develop sustainable management techniques that will drive the transition to a low-carbon future.

2. Advanced Mapping Techniques for Renewable Energy

Advanced mapping techniques are revolutionizing the renewable energy sector, enabling more precise and efficient utilization of renewable resources (Adelani, et. al., 2024, Olowe, 2018). These techniques, driven by advancements in geospatial technology and data analytics, play a critical role in the development and implementation of renewable energy projects. This article explores the key aspects of advanced mapping techniques for renewable energy and their implications for sustainable energy development.

One of the primary areas of focus in advanced mapping techniques for renewable energy is the development of innovative geological mapping techniques (Oyebode, Olowe & Makanjuola, 2023, Olowe & Adebayo, 2015). Traditional mapping methods often lack the precision and detail required for assessing renewable energy resources effectively. Advanced techniques, such as LiDAR (Light Detection and Ranging) and hyperspectral imaging, provide high-resolution data that can be used to create detailed geological maps. These maps allow for a more accurate assessment of renewable energy potential, including solar, wind, and geothermal resources.

Another key aspect of advanced mapping techniques is the precision characterization of renewable energy resources (Ahmad, et. al., 2021, Udegbe, et. al., 2024). By combining geological mapping data with meteorological and topographical data, researchers can create comprehensive models that accurately predict renewable energy potential.

These models help identify optimal sites for energy production, taking into account factors such as sunlight exposure, wind patterns, and geological features.

The selection of optimal sites for energy production is crucial for maximizing the efficiency and effectiveness of renewable energy projects (Olabi & Abdelkareem, 2022, Olowe, 2018). Advanced mapping techniques play a crucial role in this process by providing detailed information about potential sites' suitability. For example, LiDAR technology can be used to create 3D models of terrain, allowing developers to identify the best locations for solar panels or wind turbines. Additionally, advanced mapping techniques can help assess the environmental impact of renewable energy projects, ensuring that they are implemented in a sustainable and responsible manner.

Advanced mapping techniques are transforming the renewable energy sector by providing accurate and detailed information about renewable energy resources (Adeoye, et. al., 2024, Dileep, 2020). These techniques enable developers to select optimal sites for energy production, leading to more efficient and sustainable renewable energy projects. As technology continues to advance, the potential for advanced mapping techniques to further enhance the renewable energy sector is vast, offering exciting opportunities for future development.

Advanced mapping techniques for renewable energy are continuously evolving, driven by technological advancements and the increasing demand for sustainable energy solutions. One of the key areas of development is the integration of artificial intelligence (AI) and machine learning (ML) algorithms into mapping processes (Oyebode, et. a., 2015, Udegbe, et. al., 2024). These technologies enable the automated analysis of vast amounts of geospatial data, allowing for more accurate and efficient mapping of renewable energy resources.

Furthermore, advanced mapping techniques are also focusing on improving the spatial and temporal resolution of data. This includes the development of new sensors and data collection methods that can provide more detailed information about renewable energy resources. For example, advancements in satellite imaging technology have enabled researchers to capture high-resolution images of the Earth's surface, allowing for more precise mapping of solar and wind potential.

In addition, advanced mapping techniques are also being used to assess the feasibility of integrating renewable energy systems into existing infrastructure (Adelani, et. al., 2024, Owoola, Adebayo & Olowe, 2019). This includes mapping the location of existing power grids, transportation networks, and urban areas to identify opportunities for integrating renewable energy sources. By doing so, planners and policymakers can develop more effective strategies for transitioning to a renewable energy future.

Moreover, advanced mapping techniques are playing a crucial role in enhancing the resilience of renewable energy systems to climate change and natural disasters (Argyroudis, et. al., 2022 Jasiūnas, Lund & Mikkola, 2021). By mapping areas prone to extreme weather events, such as hurricanes or wildfires, developers can design renewable energy projects that are more resilient to these threats. This includes the strategic placement of renewable energy infrastructure and the implementation of backup systems to ensure continuous energy supply during emergencies. Overall, advanced mapping techniques are reshaping the renewable energy landscape by providing valuable insights into renewable energy resources, infrastructure planning, and climate resilience (Aremu, Olodo & Olaitan, 2020, Ohalete, et. al., 2022). As these technologies continue to advance, they will play an increasingly important role in accelerating the transition to a sustainable and low-carbon energy future.

3. Feasibility Assessment of Carbon Capture and Storage (CCS)

Feasibility assessment is a crucial step in determining the viability of carbon capture and storage (CCS) projects, especially in volcanic regions where geological conditions may present unique challenges and opportunities. Geological data plays a key role in this assessment, providing valuable information about the suitability of underground formations for long-term carbon storage (Ajala, et. al., 2024, Oyebode, et. al., 2020).

One of the primary uses of geological data in CCS feasibility assessment is the identification of suitable geological formations for carbon storage. This includes assessing the porosity, permeability, and sealing capacity of potential storage sites to ensure that they can securely contain injected CO_2. Geological data such as seismic surveys, well logs, and core samples are used to characterize these formations and evaluate their suitability for CCS.

In volcanic regions, the feasibility of CCS projects is influenced by the specific geological characteristics of volcanic rocks. These rocks often have unique properties, such as high porosity and permeability, which can affect the feasibility of carbon storage. Geological data is used to assess the suitability of volcanic formations for CCS, taking into account factors such as rock composition, structure, and stability (Oyebode, et. al., 2022, Udegbe, et. al., 2024). Furthermore, geological data is also used to assess the potential risks associated with CCS projects in volcanic regions. This includes evaluating the potential for CO_2leakage from storage formations and assessing the potential impacts on groundwater resources and surface ecosystems. By analyzing geological data, researchers can identify potential risks and develop strategies to mitigate them, ensuring the safe and effective implementation of CCS projects.

Overall, the utilization of geological data is essential for assessing the feasibility of CCS projects, particularly in volcanic regions. By leveraging this data, researchers and policymakers can make informed decisions about the viability of CCS projects and identify suitable geological formations for carbon storage. This, in turn, can help accelerate the deployment of CCS technology and contribute to global efforts to reduce greenhouse gas emissions and combat climate change.

In addition to identifying suitable geological formations for carbon storage and assessing risks, the feasibility assessment of CCS projects involves several other important aspects that rely on geological data. One such aspect is the evaluation of storage capacity (Gaurina-Međimurec & Mavar, 2019, Oyebode, Adebayo & Olowe, 2015). Geological data is used to estimate the volume of CO_2that can be safely stored in underground formations, taking into account factors such as the thickness of the storage reservoir, the depth at which it is located, and the geomechanical properties of the rocks. This information is crucial for determining the long-term viability of CCS projects and ensuring that they can achieve significant reductions in CO_2 emissions.

Geological data is also used to assess the injectivity of storage formations, which refers to their ability to accept CO_2 at the required rate. This involves analyzing the permeability of the rocks and their response to injection pressures to ensure that CO_2 can be injected efficiently and effectively. Assessing injectivity is critical for designing the injection wells and infrastructure needed for CCS projects.

Furthermore, geological data is used to evaluate the potential for CO_2migration and leakage from storage formations. This includes assessing the sealing capacity of cap rocks above the storage reservoir to prevent CO_2 from escaping into the atmosphere. Geological data is also used to monitor the storage site over time to detect any signs of leakage and ensure the long-term integrity of the storage reservoir (Olatunde, Adelani & Sikhakhane, 2024, Zhang, et. al., 2022). Overall, the feasibility assessment of CCS projects relies heavily on geological data to evaluate storage capacity, assess injectivity, and mitigate the risks of CO_2 migration and leakage. By leveraging this data, researchers and policymakers can make informed decisions about the viability of CCS projects and ensure that they can be implemented safely and effectively to help mitigate climate change.

4. Monitoring and Modelling Techniques

Monitoring and modeling techniques play a crucial role in the future of geological research impacting renewable energy and carbon capture (Ajala, et. al., 2024, Olowe & Kumarasamy, 2021). These techniques help assess the performance of renewable energy projects and the environmental impact of carbon capture, providing valuable data for sustainable management. Advancements in monitoring methods for renewable energy projects have significantly improved the efficiency and reliability of energy generation. For solar energy, remote sensing technologies such as LiDAR (Light Detection and Ranging) and drones are used to monitor the performance of solar panels and identify maintenance needs (Ochuba, et. al., 2024, Odeyemi, et. al., 2024). In wind energy, advanced monitoring techniques, including SCADA (Supervisory Control and Data Acquisition) systems and sensors, are used to optimize turbine performance and detect faults early.

The evaluation of long-term performance and environmental impact is essential for ensuring the sustainability of renewable energy projects (Odejide & Edunjobi, 2024, Olodo, et. al., 20217). Geological research has led to the development of models that simulate the long-term behavior of renewable energy systems and assess their impact on the environment. These models consider factors such as climate change, land use, and ecosystem health, providing valuable insights for sustainable management practices.

Geophysical and geochemical methods are used for subsurface monitoring in carbon capture projects. Geophysical techniques, such as seismic surveys, help visualize subsurface structures and identify potential storage sites for CO_2. Geochemical methods, including isotopic analysis and fluid sampling, are used to monitor the movement of CO_2 within the subsurface and assess its long-term behavior.

The integration of these monitoring and modeling techniques enables researchers and policymakers to make informed decisions about renewable energy and carbon capture projects. By continuously monitoring performance and environmental impact, stakeholders can implement sustainable management practices that maximize the benefits of renewable energy while minimizing environmental harm (Adebayo, 2022, Obaideen, et. al., 2022). Overall, future directions in geological research impacting renewable energy and carbon capture will continue to focus on advancing monitoring and modeling techniques. These advancements will enhance our understanding of renewable energy systems and carbon capture processes, leading to more sustainable management practices and a cleaner, greener future.

Monitoring and modeling techniques are integral to the future of geological research impacting renewable energy and carbon capture, offering innovative solutions for sustainable management (Ochuba, et. al., 2024, Olabi, et. al., 2022). Advancements in monitoring methods for renewable energy projects have significantly enhanced energy generation efficiency and reliability. Technologies such as LiDAR and drones enable precise monitoring of solar panels, identifying maintenance needs and optimizing performance. Similarly, advanced techniques in wind energy, such as SCADA systems and sensors, help optimize turbine performance and detect faults early, ensuring reliable energy production.

Evaluating the long-term performance and environmental impact of renewable energy projects is crucial for sustainability (Ajala, et. al., 2024, Raji, et. al., 2024). Geological research has led to the development of models that simulate the behavior of renewable energy systems over time, considering factors like climate change, land use, and ecosystem health. These models provide valuable insights for sustainable management practices, guiding decision-making processes and promoting environmental stewardship.

In carbon capture projects, geophysical and geochemical methods are used for subsurface monitoring (Macquet, et. al., 2022, Olodo, et. al., 2020). Geophysical techniques, such as seismic surveys, allow for the visualization of subsurface structures, aiding in the identification of suitable sites for CO_2 storage. Geochemical methods, including isotopic analysis and fluid sampling, help monitor the movement of CO_2 within the subsurface, assessing its long-term behavior and ensuring the effectiveness of carbon capture strategies.

The integration of these monitoring and modeling techniques enables stakeholders to make informed decisions about renewable energy and carbon capture projects. By continuously monitoring performance and environmental impact, stakeholders can implement sustainable management practices that maximize the benefits of renewable energy while minimizing environmental harm. (Ochuba, et. al., 2024, Olowe & Kumarasamy, 2017) Looking ahead, future directions in geological research will continue to focus on advancing monitoring and modeling techniques. These advancements will further enhance our understanding of renewable energy systems and carbon capture processes, leading to more sustainable management practices and a cleaner, greener future.

5. Exploration of Geological Formations for Carbon Storage

Exploration of geological formations for carbon storage is a critical component of efforts to mitigate carbon emissions and combat climate change (Ochuba, et. al., 2024, Raji, et. al., 2024). This exploration primarily focuses on two key geological formations: deep saline aquifers and depleted oil/gas reservoirs. Deep saline aquifers are underground rock formations that contain salty water and have the potential to store large volumes of CO_2. These formations are attractive for carbon storage due to their widespread distribution and large storage capacity. Depleted oil and gas reservoirs, on the other hand, are underground formations that have been emptied of their hydrocarbon resources. These reservoirs can also be repurposed for carbon storage, leveraging their existing infrastructure and geological characteristics.

To enhance storage capacity and mitigate CO_2 leakage, several strategies are employed. One approach is to carefully select sites with geological features that naturally inhibit CO_2 movement, such as impermeable cap rocks that prevent upward migration of the injected CO_2 (Olowe, Oyebode & Dada, 2015, Ololade, 2024). Additionally, engineers use advanced modeling techniques to predict the behavior of CO_2 within the storage formations over time, ensuring that it remains securely trapped underground.

Another strategy involves injecting CO_2 into the formations at pressures and temperatures that promote its conversion into a dense, liquid-like state, which enhances its storage capacity and reduces the risk of leakage (Arinze, et. al., 2024, Raji, et. al., 2024). Additionally, monitoring and verification techniques, such as seismic imaging and geochemical analysis, are employed to detect and address any potential leaks or migration of CO_2.

The exploration of geological formations for carbon storage plays a crucial role in sustainable carbon emission management (Ajala, et. al., 2024, Ofodile, et. al., 2024). By safely storing CO_2 underground, these formations help reduce the amount of CO_2 released into the atmosphere, thereby mitigating the impacts of climate change. Furthermore, carbon storage can be coupled with carbon capture technologies to create a carbon capture and storage (CCS) system, which has the potential to significantly reduce greenhouse gas emissions from industrial processes and power generation.

In conclusion, the exploration of geological formations for carbon storage is a key strategy in the fight against climate change (Ayanda, et. al., 2018, Olowe, Wasiu & Adebayo, 2019). By utilizing deep saline aquifers and depleted oil/gas reservoirs, implementing strategies to enhance storage capacity and mitigate CO_2 leakage, and contributing to sustainable carbon emission management, geological storage formations play a crucial role in reducing greenhouse gas emissions and transitioning to a more sustainable energy future.

Exploration of geological formations for carbon storage is a multifaceted process that involves a thorough understanding of subsurface geology, rock properties, and fluid behavior (Ochuba, et. al., 2024, Raji, et. al., 2024). One of the key aspects of this exploration is the identification and characterization of suitable geological formations that have the potential to safely and effectively store large volumes of carbon dioxide (CO_2) underground.

Deep saline aquifers are one of the most promising geological formations for carbon storage. These aquifers are typically located several thousand feet below the Earth's surface and are characterized by their high porosity and permeability, which make them capable of storing significant amounts of CO_2 (Jacks, et. al., 2024, Olorunsogo, Jacks & Ajala, 2024). The exploration of deep saline aquifers involves conducting geological surveys and drilling test wells to assess their suitability for carbon storage. This process requires detailed geological mapping, seismic surveys, and core sample analysis to determine the aquifer's capacity, integrity, and containment potential.

Depleted oil and gas reservoirs are another important geological formation for carbon storage. These reservoirs are the result of years of oil and gas extraction, which has left behind porous rock formations that can be repurposed for CO_2 storage (Aremu, et. al., 2015, Lottu, et. al., 2024). The exploration of depleted reservoirs involves evaluating their structural integrity, porosity, and permeability to assess their suitability for long-term carbon storage. This process often involves the use of advanced imaging techniques, such as 3D seismic surveys, to create detailed models of the reservoirs and predict their behavior under different injection scenarios.

In addition to identifying suitable geological formations, the exploration of carbon storage sites also involves assessing the potential risks and uncertainties associated with CO_2 storage. This includes evaluating the potential for CO_2 leakage, assessing the impact of CO_2 injection on local groundwater resources, and considering the potential for induced seismicity.

Overall, the exploration of geological formations for carbon storage is a complex and multidisciplinary process that requires careful planning, detailed geological analysis, and comprehensive risk assessment (Raji, et. al., 2024, Ololade, 2024). However, with the increasing need to reduce greenhouse gas emissions and mitigate climate change, the exploration of carbon storage sites is becoming an increasingly important area of research and development.

6. Challenges and Opportunities

Geological research plays a crucial role in advancing renewable energy and carbon capture technologies (Ajala, 2024, Olatunde, Adelani & Sikhakhane, 2024). However, implementing advanced geological techniques poses several challenges that must be addressed to maximize their benefits. At the same time, these challenges present opportunities for innovation and collaboration in geological research, offering new ways to overcome barriers and achieve sustainable management of energy resources.

One of the main challenges in implementing advanced geological techniques is the complexity of geological formations. Geological formations can vary widely in terms of their composition, porosity, and permeability, making it difficult to accurately predict their behavior and suitability for energy storage or carbon capture (Aremu, Aremu, & Olodo, 2015, Ochuba, et. al., 2024). Additionally, accessing deep geological formations can be costly and technically challenging, requiring advanced drilling techniques and equipment. Another challenge is the need for better integration of geological data with other types of data, such as geophysical and geochemical data, to create more accurate models of subsurface structures. This requires the development of new techniques for data integration and interpretation, as well as improved communication between geologists, geophysicists, and other experts.

Furthermore, there are challenges related to regulatory frameworks and public acceptance of geological projects (Jacks, et. al., 2024, Oladeinde, et. al., 2023). In many cases, there is a lack of clear regulations governing geological storage of CO_2 or renewable energy projects, leading to uncertainty and delays in project implementation. Public perception and acceptance of geological projects can also be a challenge, as concerns about safety, environmental impact, and land use can lead to opposition from local communities.

Despite these challenges, there are significant opportunities for innovation and collaboration in geological research. Advances in technology, such as improved imaging techniques and data analysis tools, are opening up new possibilities for understanding subsurface structures and processes (Oladeinde, et. al., 2023, Shoetan, et. al., 2024). Collaboration between researchers, industry, and government agencies can also lead to new insights and approaches for managing energy resources sustainably.

One of the key opportunities is the potential for integrating renewable energy and carbon capture technologies with geological storage (Ajala & Balogun, 2024, Okoro, et. al., 2023). For example, renewable energy sources such as wind and solar power can be used to generate electricity for carbon capture and storage processes, reducing overall emissions and increasing the efficiency of both technologies. Overall, while there are challenges to implementing advanced geological techniques, there are also significant opportunities for innovation and collaboration (Ochuba, et. al., 2024, Okoye, et. al., 2024). By overcoming these challenges and capitalizing on these opportunities, geological research can play a key role in advancing sustainable energy solutions and mitigating the impacts of climate change.

One significant challenge is the variability and unpredictability of geological formations. Geological structures can vary greatly even within a small area, making it challenging to accurately characterize and model subsurface conditions (Babatunde, et. al., 2024, Okafor, et. al. 2024). This variability can lead to uncertainties in the feasibility and performance of renewable energy projects and carbon storage sites. Addressing this challenge requires the development of more sophisticated modeling techniques that can account for this variability and provide more accurate predictions.

Another challenge is the need for sustainable management of geological resources. As the demand for renewable energy and carbon storage grows, there is a risk of overexploitation of geological formations (Edunjobi, 2024, Ogundipe, Odejide & Edunjobi, 2024). This can lead to environmental degradation, depletion of resources, and conflicts over land use. Sustainable management practices, such as integrated resource planning, stakeholder engagement, and ecosystem-based approaches, are essential to ensure the long-term viability of geological resources for renewable energy and carbon storage.

On the other hand, there are several opportunities for innovation and collaboration in geological research. One opportunity is the development of new technologies for exploring and characterizing geological formations (Ikumapayi, et. al., 2022, Ochuba, et. al., 2024). Advances in remote sensing, geophysical imaging, and data analytics are opening up new possibilities for understanding subsurface structures and properties. These technologies can help to reduce the cost and environmental impact of geological exploration and improve the accuracy of resource assessments.

Additionally, there is an opportunity to enhance international collaboration and knowledge sharing in geological research (Farayola, et. al., 2023, Igah, et. al., 2023). Many countries are facing similar challenges in energy and environmental management, and collaboration can help to accelerate progress and reduce duplication of effort. By sharing data, best practices, and research findings, countries can benefit from each other's experiences and expertise.

Overall, while there are significant challenges in advancing geological research for renewable energy and carbon capture, there are also many opportunities for innovation and collaboration (Hassan, et. al., 2024, Nageri, et. al., 2013). By addressing these challenges and capitalizing on these opportunities, geological research can play a crucial role in advancing sustainable energy solutions and mitigating climate change.

7. Conclusion

In conclusion, the future directions in geological research impacting renewable energy and carbon capture present a multifaceted landscape of challenges and opportunities. Throughout this exploration, several key points have emerged. Firstly, advanced mapping techniques offer promise in precisely characterizing renewable energy resources and selecting optimal sites for energy production. Additionally, feasibility assessments of carbon capture and storage (CCS) projects, especially in volcanic regions, underscore the importance of utilizing geological data for identifying suitable geological formations and enhancing storage capacity.

Moreover, monitoring and modeling techniques play a crucial role in evaluating the long-term performance and environmental impact of renewable energy projects and CCS initiatives. These methods, including geophysical and geochemical approaches, provide invaluable insights into subsurface dynamics and facilitate informed decision-making.

Exploration of geological formations for carbon storage reveals the potential of deep saline aquifers and depleted oil/gas reservoirs in contributing to sustainable carbon emission management. Strategies for enhancing storage capacity and mitigating CO_2leakage are essential for ensuring the effectiveness and integrity of CCS projects.

Despite the challenges posed by geological variability and resource management, there are ample opportunities for innovation and collaboration. Advanced technologies and international cooperation can drive progress in geological research, accelerating the development of sustainable energy solutions and climate change mitigation strategies.

Therefore, a call to action is warranted for continued research and collaboration in this field. The importance of geological research in shaping sustainable energy and climate solutions cannot be overstated. By leveraging geological insights and fostering interdisciplinary cooperation, we can overcome challenges, capitalize on opportunities, and pave the way towards a more sustainable and resilient future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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