

Bridging Cleantech and Fintech: A Workflow for 3D Visualization, Multi-Source Data Integration, and Blockchain-Based Management of Subsurface Reservoirs

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Introduction

The energy finance sector faces systemic challenges due to a lack of cohesion between technological advancements and financial systems, resulting in siloed operations and opaque data flows. This fragmentation hinders the integration of financial investments with scientific insights, leading to inefficient short-term-focused strategies. One of the critical challenges lies in carbon accounting, where transparency deficits and unreliable data impede accurate emissions tracking, collaboration, and the decarbonization of energy systems. Additionally, the disconnect between computer science and earth science solutions has limited the integration of advanced technologies into geological and environmental frameworks, further complicating efforts to establish cohesive carbon accounting systems.

To address these challenges, this work proposes a comprehensive workflow that combines 3D visualization of subsurface reservoirs derived from legacy 2D seismic data with blockchain integration and multi-source data validation. The workflow begins with the extraction and processing of 2D seismic data, which is extrapolated into 3D representations using Python-based tools and geological interpolation methods. Gaps in the seismic data are addressed by integrating diverse datasets, including topographic data to refine surface-to-subsurface relationships, well-log data to improve vertical resolution, and geochemical data to validate reservoir characteristics such as fluid composition and mineral content.

A blockchain-based ledger is then employed to record and manage all integrated datasets, creating an immutable and transparent system for tracking data provenance, resource transactions, and emissions over time. The blockchain is enhanced with quantum-resilient cryptographic methods and energy-efficient consensus mechanisms, reducing computational overhead while ensuring security and alignment with sustainability goals. By following the entire carbon lifecycle from its subsurface origins, this system provides precise and actionable insights for reducing environmental impacts and advancing carbon accounting frameworks.

The workflow also incorporates future-oriented approaches, such as quantum sensing and dualistic validation, to optimize energy systems, enhance resource utilization, and achieve significant reductions in energy consumption for digital infrastructure. These innovations establish a scalable and accurate framework for managing injected subsurface reservoirs with transparency and accountability. By bridging the gaps between cleantech and fintech, this integrated system supports sustainable resource management and enables the development of high-performance digital ecosystems essential for the global energy transition.

Workflow for 3D Visualization and Data Integration from GEUS-Jutland Dataset

Data Extraction

The workflow begins by accessing the GEUS-M-Jutland subsurface dataset through the official GEUS data repository. The dataset, which includes 2D seismic data and associated metadata, is retrieved in a format optimized for subsequent processing. This step ensures that the foundational data is comprehensive and suitable for detailed analysis, serving as the basis for constructing advanced subsurface models and integrating additional data layers. By leveraging this publicly available dataset, the methodology aligns with transparent and reproducible research practices, enabling accurate representation of the subsurface environment.

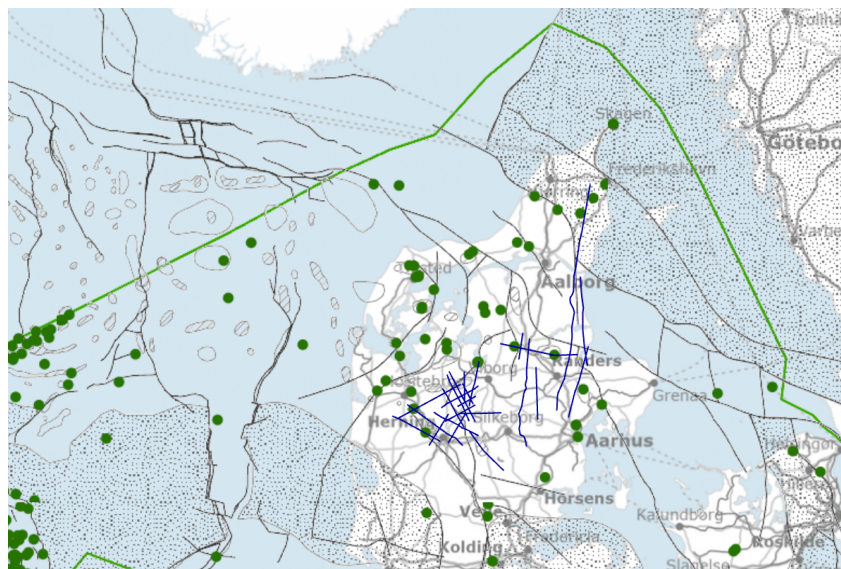


Figure 1. Visualization of subsurface seismic data from the GEUS-M-Jutland dataset. Source: *GEUS-M-Jutland Subsurface Dataset*. Geological Survey of Denmark and Greenland, 2023. Retrieved from https://data.geus.dk/ugdata2d3d/procsum.html?proc_id=17304.

2D Data Processing and Visualization in 3D

The 2D seismic data is processed using Python-based libraries such as **NumPy**, **Matplotlib**, and **PyVista** to identify key subsurface features, including potential reservoir structures. This processing step involves data cleaning, filtering, and the application of computational algorithms to enhance the resolution and clarity of seismic reflections. Subsequently, the processed 2D data is extrapolated into a 3D representation by interpolating missing dimensions, leveraging established geological and structural patterns as constraints. This interpolation enables the construction of a 3D model that provides an initial visualization of the subsurface reservoir geometry, serving as a foundational tool for further analysis. The integration of this 3D visualization into the workflow enhances the interpretability of the data and facilitates more accurate decision-making in reservoir characterization.

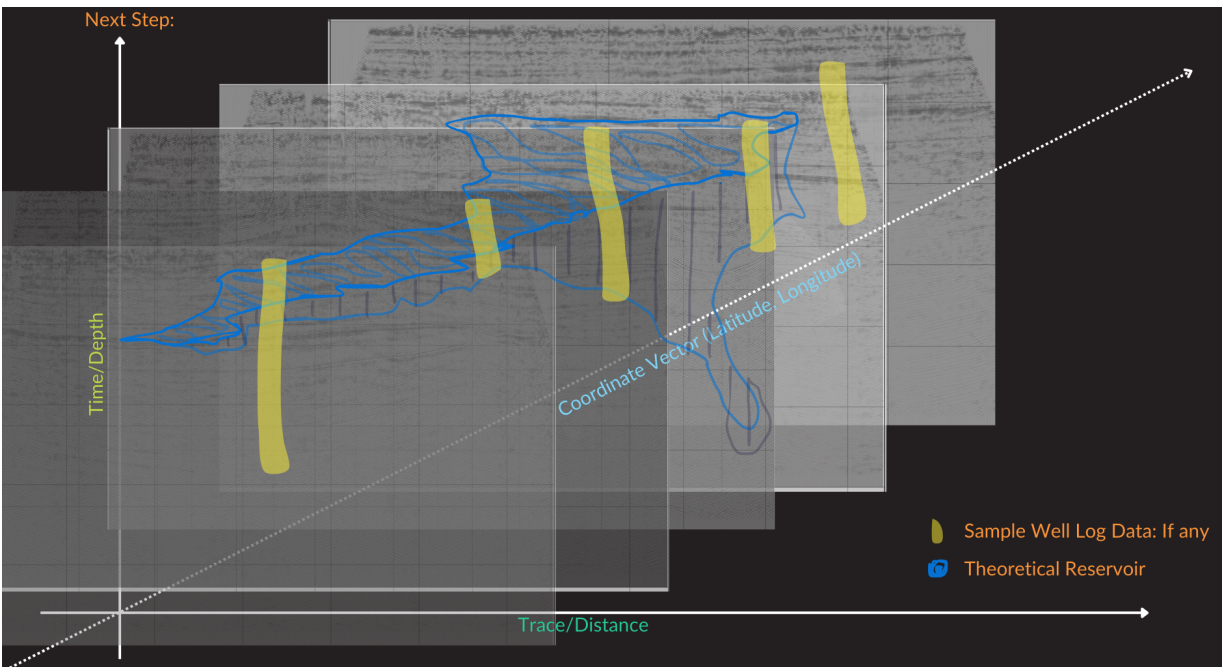


Figure 2. 3D Visualization Pulled from Processed 2D GEUS-M-Jutland dataset via Python.

Multiple Data Integration for Enhanced Accuracy, Validation, and Output

To address geospatial gaps in the seismic data, additional datasets will be integrated to enhance the accuracy and resolution of the model. Some examples of data types are: Topographic data will be utilized to refine the relationships between surface features and subsurface structures, providing a more coherent understanding of the geological context. Well log data will be incorporated to improve vertical resolution by correlating stratigraphic layers with observed seismic patterns, offering critical insights into the subsurface's physical and geological properties. Geochemical data will be applied to validate the presence of specific reservoir characteristics, such as fluid composition and mineral content, ensuring that the model accurately represents the subsurface environment. Furthermore, any kind of earth data can be integrated into the workflow, where the inclusion of diverse data types will enhance model accuracy through improved validation.

The integrated dataset will then be validated for consistency and accuracy by comparing the generated model against known geological markers, ensuring reliability and scientific rigor. The final output will be a high-resolution 3D visualization of the injected subsurface reservoirs, enriched with multi-source data and securely documented using blockchain technology for transparency and traceability. This workflow, summarized in **Figure 3**, highlights the step-by-step integration and validation process, culminating in a robust and comprehensive subsurface model that supports precise reservoir characterization and decision-making.

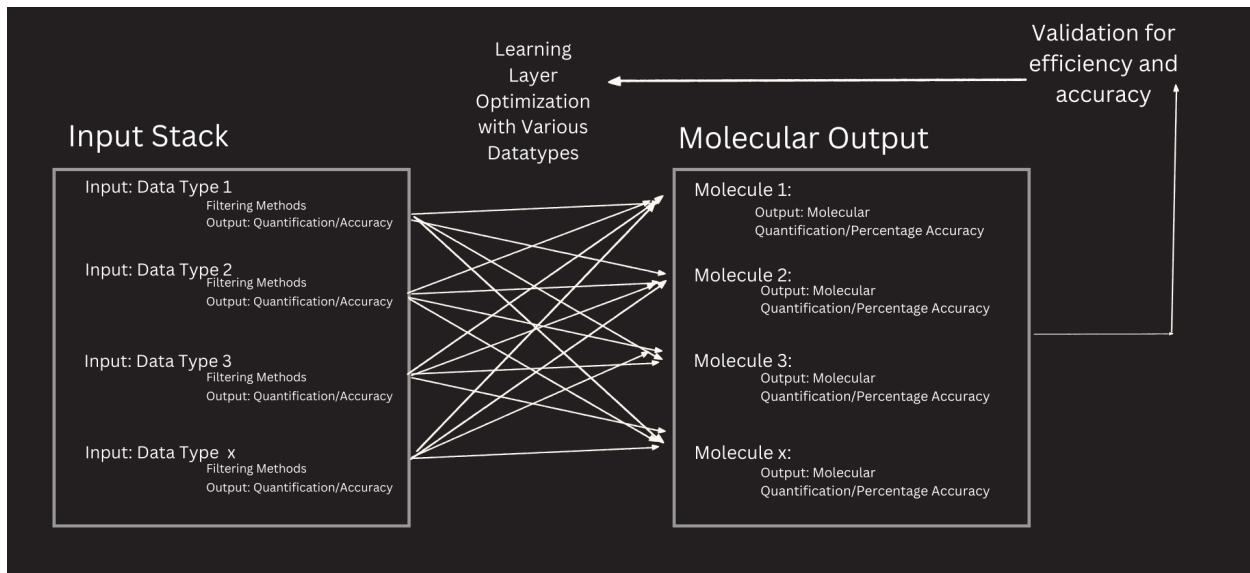


Figure 3. A comprehensive workflow illustrating the integration of multiple data types to address geospatial gaps, validate accuracy, and produce high-resolution 3D reservoir visualizations.

Blockchain Integration

Once the 3D reservoir visualization is complete, the resulting data will be integrated into a blockchain-based ledger to ensure transparency, traceability, and secure data management. Each dataset—such as seismic, topographic, well-log, geochemical, subsurface microbial—will be recorded as a transaction within the blockchain, creating an immutable and auditable record of all integrated information. This approach provides stakeholders with the ability to monitor the integrity of the dataset and track the evolution of reservoir models over time, ensuring that any updates, modifications, or additions are documented with full accountability.

The blockchain framework enhances data security, promotes collaboration, and enables precise tracking of resource characterization and environmental impact assessments. As illustrated in Figure 4: Blockchain-Based Ledger for Multi-Source Data Validation and Reservoir Model Evolution, this system acts as a centralized ledger for securely managing diverse datasets while providing real-time insights into the lifecycle of subsurface models. This technical integration bridges the gap between geoscience and digital resource management, supporting long-term sustainability and transparency goals.

	Extraction Transaction	Production Transaction	Distribution Transactions	Revenue Potential
Methane (CH ₄)	Marginal fee per cubic meter of methane extracted	Fee based on methane converted to energy (e.g., kWh in natural gas plants)	Fee per cubic meter of methane transported through pipelines or LNG shipping.	High in regions with active natural gas extraction and distribution networks.
Hydrogen (H ₂)	Marginal fee per kilogram of hydrogen extracted from reservoirs.	Fee on hydrogen processed for fuel or industrial applications.	Fee per kilogram of hydrogen delivered via pipelines or tankers.	Growing with the shift to hydrogen economies and renewable energy integration.
Carbon Dioxide (CO ₂)	Marginal fee per ton of CO ₂ captured or extracted for industrial use.	Fee per ton of CO ₂ processed or stored in carbon capture facilities.	Fee per ton of CO ₂ transported for storage or industrial applications.	Moderate, with increasing demand for carbon capture and storage solutions.
Helium (He)	Marginal fee per cubic meter of helium extracted.	Fee on helium refined and prepared for commercial use.	Fee per cubic meter of helium transported to end-users or industries.	Niche but valuable, given helium's importance in high-tech applications.

Figure 4. Blockchain-Based Ledger for Multi-Source Data Validation and Reservoir Model Evolution

Conclusions

The proposed workflow demonstrates the potential of integrating 3D visualization, multi-source data validation, and blockchain technology to enhance the transparency, accuracy, and sustainability of subsurface reservoir management. However, the success of this system hinges on its adoption by oil and gas companies and its recognition by financial institutions involved in issuing carbon credits and sustainable bonds. Accurate tracking of carbon flows, from subsurface origins to emissions, requires widespread adoption of blockchain as a standard for transparent, immutable data recording.

Incorporating blockchain into the oil and gas industry would not only improve operational accountability but also bridge critical gaps in carbon accounting frameworks. This alignment is essential for building trust in the carbon market, where the ability to measure, verify, and report emissions plays a pivotal role in the valuation and issuance of carbon credits. Financial institutions must also integrate blockchain-verified datasets into their criteria for sustainable bonds, ensuring that investments are backed by reliable and science-driven data.

Without such alignment, efforts to reduce carbon footprints and scale decarbonization initiatives risk falling short due to inefficiencies and data opacity. By enabling a transparent and traceable framework, this approach can support the growth of a robust carbon market and incentivize industries to adopt sustainable practices. Ultimately, achieving the global energy transition requires not just technological innovation but also a collaborative effort to align financial and operational systems with sustainability goals. Blockchain, as a cornerstone of this framework, has the potential to transform the energy sector into a more accountable and efficient ecosystem.

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References

GEUS-M-JUTLAND. (2024). M-Jutland subsurface dataset. Geological Survey of Denmark and Greenland. Retrieved from https://data.geus.dk/ugdata2d3d/procsum.html?proc_id=17304.