HUB TECH IA

Deliverable report 37

AI and IAGEN Application Use Case

Exploration: Reserve Prediction for Accurate Estimation of Recoverable Gas Volume in Vaca Muerta, Neuquén, Argentina

I. Introduction

The Vaca Muerta Formation extends over approximately 30,000 square kilometers within the Neuquén Basin, located in the northern Patagonia region of Argentina, encompassing the provinces of Neuquén, Río Negro, La Pampa and Mendoza. This geological formation, dating from the Late Jurassic to Early Cretaceous periods, is predominantly composed of marls, black shales and argillaceous limestones. Globally recognized as one of the largest shale oil and gas deposits, Vaca Muerta is positioned as a highly relevant strategic asset in the global energy context. Vaca Muerta's vast extent and resource potential make it a crucial element for Argentina's energy future and a significant player in the international unconventional gas landscape.

Accurately estimating gas reserves in formations like Vaca Muerta is of fundamental importance for several reasons.

First, it provides the basis for long-term energy planning at the national level, enabling governments and businesses to make informed decisions about security of supply and diversification of the energy mix.

Second, it directly influences infrastructure investment decisions, including the construction of gas pipelines, processing plants, and export terminals. Accurate reserve estimates are essential to justify these multi-billion-dollar investments and ensure their long-term profitability.

Third, reserve forecasting impacts export strategies and economic projections, as Vaca Muerta's potential to become a net gas exporter has significant implications for Argentina's trade balance and foreign exchange earnings. An underestimation of reserves could lead to lost market opportunities, while an overestimation could result in unsustainable investments and inflated economic expectations. Finally, a correct reserve assessment is crucial for the formulation of coherent energy policies and for the efficient management of natural resources.

This report is structured as follows: Initially, it examines current production and gas reserve estimates in Vaca Muerta, based on recent studies and reports.

The various methodologies and models used for shale reserve prediction are then investigated, including both deterministic and probabilistic approaches. Key geological and engineering factors that influence the accurate estimation of recoverable gas volumes are analyzed in detail, as are recent technological advances in unconventional gas exploration and production.

II. Using AI and IAGen in Gas Reserve Prediction

1. Role of Traditional AI

Classical AI can significantly improve the accuracy and efficiency of reserve estimation through techniques such as:

- Automated Decline Models: Algorithms that automatically adjust production curves (ARPS, logarithmic, etc.) and project future scenarios with minimal human intervention.

- Supervised Machine Learning: Models such as linear regression, random forest, or neural networks trained with historical data from similar wells to predict recoverable volumes.

- Stochastic Simulation (Monte Carlo): Generation of thousands of reservoir behavior scenarios in response to variations in key parameters, to estimate probable reserves (P10, P50, P90).

2. Role of Generative Artificial Intelligence (IAGen)

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on creating new content, such as models, images, code, or text, from existing data. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate new and original content that is often indistinguishable from human-created content.

IAGen complements and amplifies the power of traditional AI, adding:

Natural Language Understanding and Automated Technical Explanation

- Translate complex technical results (such as probabilistic estimates) into reports readable by managers or regulators, with clear language and reasoned reasoning.

- Develop automated justifications for why one prediction is more reliable than another.

Multimodal Reasoning on Technical Data

- You can directly read files (PDFs, CSVs, charts, production reports) and draw intelligent conclusions by combining text, numbers, and business context.

Reengineering of Estimation Models

- Generate, compare, and improve customized prediction models based on reservoir type, reservoir behavior, and project objectives.

- Proposes improvement strategies (e.g.: increase pressure, change fracture design, optimize flow rates).

Automation of Reports and Interfaces

- Create automated dashboards, technical presentations, and executive summaries.

It can be integrated into platforms such as Power BI, Notion, Google Drive, or SCADA environments, functioning as a technical copilot.

3. Key Benefits of the AI + IAGen Approach

Benefit	Description
🎯 Greater Accuracy	Reduces the uncertainty of manual or empirical estimates.
⏱ Speed	Speed up studies that previously took weeks.
📈 Scalability	Adapts to hundreds of wells simultaneously.
💡 Contextual Intelligence	It offers actionable recommendations based on the economic, technical and geological context.
🧠 24/7 Support	It works like a virtual engineer that never stops.

III. **Using AI with agents**

1. **IAGEN Agents Concept**

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, enabling the development of systems capable of generating content, answering complex questions, and assisting with highly demanding cognitive tasks. From this capability, a new technological architecture has emerged: GAI-powered agents. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, execute tasks, and learn from their interactions with the environment.

An IAGen agent combines large language models with additional components such as external tools, memory, planning, and autonomous execution. This allows them to operate in complex environments, with the ability to break down objectives into steps, coordinate multiple actions, interact with digital systems (such as databases, APIs, or documents), and adapt to context changes in real time. These qualities distinguish them from traditional chatbots and open up a range of more sophisticated and customizable applications.

At the organizational level, these agents are being used to automate processes, generate data analysis, assist in decision-making, and improve the user experience, both internally and externally. For example, they can take on human resources, legal, financial, or logistics tasks, and even tasks linked to the technical areas of production processes, acting as intelligent assistants that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way organizations can scale their operations without losing quality or control.

Furthermore, agentic workflows—structures where multiple agents collaborate to solve complex problems—allow responsibilities to be distributed among different agent profiles, each with specific functions. This creates hybrid work environments where humans and agents coexist, optimizing time, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs, or document management platforms further expands their capabilities.

The development of IAGen-powered agents represents a crucial step toward a new era of intelligent automation.

Among the benefits of authentic workflows powered by generative AI models is the ability to automate entire production processes, end-to-end, and even add value by leveraging the capabilities of language models based on these technologies.

However, its implementation also poses technical, ethical, and legal challenges, ranging from responsible design to human oversight. Therefore, understanding its architecture, operational logic, and potential impacts is critical for its effective and safe adoption in diverse professional contexts.

2. Aim

Accurately estimate the volume of technically and economically recoverable gas by combining historical data, reservoir parameters, production behavior, and scenario simulations.

3. Agent design proposal powered by IAGEN

Data Entry (Input Layer)

- PVT data (pressure, volume, temperature)
- Production history
- Petrophysical properties (porosity, permeability, saturation)
- Geological and static modeling data
- Declination curves (Arps, etc.)

- Economic conditions (gas price, costs)

4. Agent Workflow

- **Data Upload (Google Drive, SCADA API, Excel)**
- → Automatic cleaning and validation
- → Modeling with multiple techniques
- → Comparison of results
- → Scenario simulation
- → Interpretation by LLM
- → Export of technical-economic report

5. Expected Departures

- Estimated recoverable volume: [X] MMscf
- Baseline scenario (P50), optimistic (P10), conservative (P90)
- Declination, uncertainty, sensitivity graphs
- Recommendations for optimization (drilling, fracturing, secondary recovery)

- Report in clear language for decision-makers

6. Intelligent Agent Modules

- **Decline Analysis Module**
  This component automatically adjusts production curves using models such as Arps, hyperbolic, exponential, and other more advanced models. The system selects the optimal model based on the well's historical behavior and projects estimated future production. This analysis is key to calculating the technical recoverable volume.
- **Anomaly Identification Module**
  Implements outlier detection and cross-validation techniques to identify inconsistencies in input data, such as implausible pressure records, production outliers, or abrupt changes that could alter predictions. The agent generates alerts and suggestions to correct these data before modeling.
- **Probabilistic Simulation Module**
  Uses Monte Carlo simulations to assess uncertainties. Using key variables (such as porosity, permeability, initial pressure, and flow rates), it generates thousands of possible scenarios and calculates probabilistic reserve estimates: P10 (optimistic), P50 (medium), and P90 (conservative).
- **Machine Learning Prediction Module**
  Uses supervised learning algorithms (such as random forest, XGBoost, or neural networks) trained on historical data from similar wells to estimate recoverable gas volume based on multiple technical variables. The system learns complex nonlinear patterns that improve accuracy compared to conventional methods.
- **Technical Explainer Module (LLM)**
  This component interprets the results of previous models and generates natural language explanations. It details why a model was chosen, which variables were most influential, and provides a technical summary for engineers or a simplified one for non-technical decision-makers.
- **Model Comparator Module**

Evaluates different prediction and decline techniques used in the process. It compares metrics such as R^2, mean square error, and generalization capability to automatically select the best model for the reservoir or well being analyzed.

- **Report Generator Module**
  Automates the creation of technical and executive reports. It includes numerical results, production graphs and projections, sensitivity analysis, key findings, and recommendations. Documents can be exported to PDF or Word, or integrated into interactive dashboards.

IV. Methodologies and Models for Predicting Gas Reserves in Shale Formations

Reserve estimation in shale formations such as Vaca Muerta is performed using a variety of methodologies and models, which can be broadly classified into deterministic and probabilistic approaches.

Deterministic methods rely on the use of a single estimated value for each relevant geological and engineering parameter to calculate a single reserve value. These methods include volumetric methods, which estimate the original gas in place (GOES) from parameters such as gross rock volume, porosity, gas saturation, and gas volume factor.

Another commonly used deterministic method is decline curve analysis (DCA), which extrapolates historical production trends to predict future production and, ultimately, recoverable reserves. While these methods provide a straightforward estimate, they may not adequately reflect the uncertainties inherent in the properties of shale reservoirs, which are often highly heterogeneous.

Probabilistic methods, on the other hand, seek to quantify the uncertainty associated with reserves estimation by assigning probability distributions to the input parameters. A widely used probabilistic technique is Monte Carlo simulation, which generates multiple reserves scenarios based on random sampling of the probability distributions of the input parameters, providing a range of possible outcomes (e.g., P10, P50, P90) and an assessment of the probability associated with each. These methods offer a more complete understanding of reserves potential by considering the variability of reservoir parameters.

In practice, hybrid approaches that combine elements of deterministic and probabilistic methods are often employed. For example, a deterministic method may be used to obtain an initial reserve estimate, while a probabilistic analysis is applied to assess the uncertainty associated with that estimate. This combination can provide greater confidence in reserve assessment.

There are also specific models developed for reserve prediction in shale deposits. They can be used for production forecasting and reserve estimation in these types of formations.

As shale fields progress through their development phase, there is a trend away from predominantly deterministic methods to more probabilistic approaches. Furthermore, the increasing availability of production and reservoir characterization data is driving the use of data-driven approaches and machine learning techniques to improve the accuracy of reserve predictions.

V. Key Geological and Engineering Factors Influencing Gas Recovery in Vaca Muerta

Accurate estimation of the recoverable gas volume in Vaca Muerta is intrinsically linked to a series of geological and engineering factors that determine well productivity and extraction efficiency.

Among the most relevant geological factors are the porosity and permeability of the formation, which determine the storage capacity and ease of gas flow. In Vaca Muerta, porosity varies between 4% and 14%. Total organic carbon (TOC) content is another crucial factor, as it indicates the hydrocarbon richness of the source rock; in favorable sectors of Vaca Muerta, the average TOC is 5%. The thermal maturity of the formation influences the type of hydrocarbon produced, from dry gas to black oil. The thickness of the shale layer, which in Vaca Muerta varies considerably between 60 and 520 meters, directly impacts the quantity of in-situ resources. The mineralogy of the rock, including the presence of carbonate cement, affects the hardness of the lithology. The existence of natural fracture networks can increase permeability and facilitate gas flow. Finally, rock geomechanical properties such as Young's modulus and Poisson's ratio are important for optimizing fracture growth induced during stimulation. The complex and heterogeneous geology of Vaca Muerta presents both opportunities and challenges for reserve estimation and efficient production.

Regarding engineering factors, reservoir pressure and temperature are critical, as they influence gas volume and flow rate. The presence of high pore pressure is a characteristic of Vaca Muerta. Drilling techniques, especially horizontal drilling and multistage hydraulic fracturing, are essential for the economic production of shale gas.

Well spacing and completion strategies are designed to maximize drainage and recovery. Hydraulic fracturing parameters, such as proppant type and volume, injection pressure, and number of fracturing stages, have evolved significantly, with a notable increase in proppant intensity. Enhanced recovery (EOR) techniques, including novel processes, are being investigated to increase the recovery factor.

Finally, controlled pressure drilling (MPD) is used to mitigate gas influxes and maintain wellbore stability. Innovation and optimization in engineering practices are crucial to overcoming geological challenges and unlocking the productive potential of Vaca Muerta.

VI. Challenges and Uncertainties Associated with Reserve Prediction in Shale Formations

Predicting reserves in shale formations presents inherent challenges and uncertainties due to the unique characteristics of these reservoirs.

One of the main sources of uncertainty lies in the geological heterogeneity and anisotropy of shale reservoirs. The complex network of natural and induced fractures, coupled with long periods of transient flow, make it difficult to predict long-term production behavior. Furthermore, there is significant variability in production performance between wells, complicating the extrapolation of results to large areas.

Data limitations also contribute to uncertainty. Compared with conventional reservoirs, shale reservoirs typically have shorter production histories and more dispersed geological sampling. Availability and access to quality data can be challenging , affecting the robustness of prediction models.

Reserve estimates are highly sensitive to key variables that are difficult to define precisely. The recovery factor (the proportion of the original gas in place that is expected to be recovered) is one such variable, as is the estimated ultimate recovery (EUR) of individual wells. Assumptions about future technological advances and economic conditions also introduce uncertainty into long-term predictions.

The industry is addressing these uncertainties by using probabilistic methods to quantify the range of possible outcomes. Sensitivity analysis is used to identify variables that have the greatest impact on reserve estimates. Estimates are continually revised as more production data become available. Comparing deterministic and probabilistic approaches also helps validate and improve the reliability of predictions. Despite these efforts, accurate reserve prediction in shale formations remains a complex challenge requiring the integration of geological, engineering, and economic knowledge, as well as the application of advanced technologies.

It is recommended to promote short-term investment in AI agent implementation teams in technology and training: Investment is required in proofs of concept and pilot tests. The focus here must be on training the talent to implement them, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in the design and implementation of AI agents. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.

VII. **Conclusion and Recommendations**

In short, the Vaca Muerta formation represents a shale gas resource of global proportions, with significant potential to transform the energy landscape of Argentina and the region. Current production is trending upward, and estimates of technically recoverable reserves place it among the largest in the world. However, fully realizing this potential faces challenges related to infrastructure, geological uncertainty, and environmental considerations.

To improve the accuracy of gas reserve estimates in Vaca Muerta, it is recommended:

- Increase investment in the acquisition of detailed geological and engineering data, including well logs, core analysis, and production testing.
- Develop and apply advanced probabilistic models that incorporate the specific geological characteristics of Vaca Muerta and allow for better quantification of uncertainty.
- Promote the exchange of data and best practices among operating companies, research institutions, and government agencies.
- Continuously monitor well production performance to refine reserve estimates over time.

To maximize the sustainable development of Vaca Muerta's gas resources, it is suggested:

- Prioritize the development of the infrastructure necessary for the transportation, processing, and export of gas, including the expansion of gas pipelines and the construction of LNG terminals.
- Implement and enforce robust environmental regulations and adopt industry best practices to mitigate environmental impacts associated with shale gas production.
- Establish open and constructive dialogue with local communities, including indigenous communities, to address their concerns and ensure that the benefits of development are distributed equitably.
- Promote a stable and attractive investment climate through consistent and

transparent energy policies.

In conclusion, Vaca Muerta is a strategic asset of great importance for Argentina. Its responsible and efficient development, based on a precise understanding of its reserves and the adoption of sustainable technologies and practices, can significantly contribute to the country's energy security, boost its economic growth, and strengthen its position in the global energy market.

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