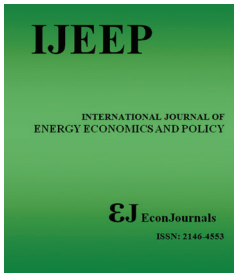

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Upstream Gas Portfolio Optimization under Fiscal Rules and Uncertainty: A Systematic Review and Bibliometric Mapping

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ABSTRACT

This study combines a systematic review (in accordance with PRISMA) and bibliometric mapping (VOSviewer and Bibliometrix) to explain how upstream gas portfolio decisions are optimized when fiscal rules limit annual cash flow. The Scopus 2005-2025 corpus of Title–Abstract–Keywords searches (1,149 records) confirm two pillars of the method: stochastic/robust optimization for portfolio sequencing and real options for flexibility in investment time and scale. Trend analysis, intellectual networks, and keyword evolution show the dominance of analytical-decision and reservoir planning themes; conversely, fiscal overlays such as withdrawal caps, cash-flow/budget constraints are still rarely formalized in mainstream models. The SLR synthesis shows that explicitly coding multi-period liquidity constraints materially changes project selection, sequencing, peak cash, and break-even timing compared to the baseline without constraints. The policy implication is a shift from hard caps to multi-period designed caps (with liquidity floors and countercyclical elements) integrated directly into the optimization framework. To balance value and fiscal stability, we recommend a gas-centric and modular portfolio that pairs ENPV with downside risk control objectives (e.g., CVaR/peak cash minimization). The main contribution of this study is to map fiscal gaps in the optimization literature and propose a research direction towards an integrated stochastic–real options framework with an overlay of fiscal rules that enables policy frontier reporting (value vs. stability).

Keywords: Upstream Gas, Portfolio Optimization, Fiscal Rules, Capital Rationing, Stochastic Optimization, Real Options, Cash-flow Constraints
JEL Classification: Q41, Q48, Q35, C61, G11, D81, E62

1. BACKGROUND

Investments in upstream gas infrastructure, including pipelines, gas hubs, LNG, FLNG, and field development plans, encounter dual uncertainties: fluctuations in commodity prices and variations in resource and production profiles. Concurrently, decision-makers are limited by capital rationing and fiscal regulations that impose restrictions on annual cash flows, such as withdrawal caps and budget constraints. An analysis of the Scopus corpus (approximately 1,100 documents) indicates the preeminence of optimization and decision analysis in the selection and sequencing of development planning projects, as well as in capacity expansion, incorporating value and risk assessment under uncertainty (Tarhan et al., 2009; Gupta and Grossmann, 2014, 2017; Bakker et al., 2021; Beck and Bickel, 2022). Research in multi-stage stochastic programming formalizes sequential decision-making under uncertainty in pricing and production, yielding investment schedules that exhibit greater resilience to market shocks and adjustments in reserve information (Tarhan et al., 2009; Gupta and Grossmann, 2014).

The real options literature, however, underscores the need of temporal and spatial flexibility in delaying, expanding, or altering LNG monetization paths compared to pipelines, in order to minimize volatility while utilizing incremental options (Bakker et al., 2021; Beck and Bickel, 2022; Noshchenko and Hagspiel, 2024). The collaboration between the two establishes a basis for evaluating the value–risk–fiscal resilience trade-offs in infrastructure portfolios.

Nonetheless, the policy-financing gap is evident: a limited number of research explicitly incorporate multi-period fiscal rules or financial limitations into stochastic portfolio or scheduling models, despite recommendations in the process optimization literature (Gupta and Grossmann, 2014, 2017). For governments and state-owned oil and gas enterprises, cash flow dynamics, break-even periods, peak liquidity, and revenue consistency are equally significant as (E)NPV. This study employs a Systematic Literature Review (PRISMA) alongside bibliometric mapping (Bibliometrix/VOSviewer) to delineate the current state of research and pinpoint gaps and opportunities for cross-method integration (Tarhan et al., 2009; Gupta and Grossmann, 2014, 2017; Bakker et al., 2021; Beck and Bickel, 2022; Noshchenko and Hagspiel, 2024; also Zupic and Čater, 2015; Aria and Cuccurullo, 2017; Donthu et al., 2021).

Methodologically, decisions on upstream infrastructure sequencing and fiscal sustainability are commonly approached using multistage stochastic programming and decomposition (Dantzig & Madansky, 1961; Ahmed & García, 2003; Ahmed et al., 2003; Birge & Louveaux, 2011), process and energy system planning under uncertainty (Goel & Grossmann, 2004; van den Heever & Grossmann, 2001; Gümüş & Floudas, 2007), and real options for valuing flexibility under irreversible investment (Pindyck, 1991; Dixit & Pindyck, 1994; Cortazar et al., 2001; Brandão et al., 2005; Fernandes et al., 2011; Trigeorgis, 1996; Trigeorgis & Tsekrekos, 2018). In addition, performance and resilience based indicators for structural systems and infrastructure networks provide complementary lenses to support risk aware sequencing decisions (Ghosn et al., 2016).

Related energy economics evidence also examines investment and market uncertainty in gas and LNG, and real options valuation of offshore field development under different pricing regimes (Fleten & Näsäkkälä, 2010; Reinelt & Westgaard, 2011; Goto et al., 2017; Eshragh & Gossner, 2018)

On the infrastructure side, optimization of pipeline scheduling, expansion, and supply under uncertainty has been studied in gas transportation systems (He & Guo, 2017; Ríos-Mercado & Borraz-Sánchez, 2015; Zhang & Li, 2019; Wang & Li, 2019), while risk based integrity management is also relevant for resilient network planning (Xie & Tian, 2018).

At the macro level, the depletion and management of natural resource wealth and energy growth linkages motivate fiscal rules and intertemporal policy design (van der Ploeg & Venables, 2012; Shafiee & Topal, 2010; Sequeira et al., 2014).

This study seeks to systematically delineate trends, methodological clusters, and economic-policy indicators utilized (ENPV, CVaR/risk, peak cash, break-even time, and cash-flow profile); evaluate the degree to which fiscal rules/capital rationing, including withdrawal caps and multi-period cash-flow constraints, are explicitly integrated into portfolio/stochastic scheduling models and their implications; synthesize the influence of real options on monetization path decisions (LNG versus pipeline), phasing (including marginal fields), and expansion scale amid uncertainty; and articulate the ensuing methodological gaps and research agenda towards a stochastic-real options framework incorporating fiscal rules. A bibliometric analysis on Upstream Gas Portfolio Optimization within the context of Fiscal Rules and Uncertainty was performed to address the subsequent research inquiries:

1. RQ1 - Mapping 2005-2025: What is the publication/citation trends, methodological clusters, intellectual structure, and most-used economic–policy indicators for upstream-gas portfolio optimization (NPV/ENPV, CVaR, peak cash, time-to-break-even, cash-flow profiles)?
2. RQ2 - Fiscal Regulations within the Model: Fiscal rules/capital rationing e.g., withdrawal limitations and multi-period cash-flow constraints are explicitly modeled how often and how do they affect project selection, sequencing, cash-flow peaks, and time-to-break-even against unconstrained baselines?
3. RQ3 - Flexibility (real options): How do timing/scale flexibilities (defer, expand, abandon/switch) improve monetization choices (LNG vs. pipeline), phasing, and scale under price and production uncertainty?
4. RQ4 - Integrative Framework: What features and reporting practices make effective multi-stage stochastic/robust frameworks that integrate portfolio sequencing, capacity expansion, and fiscal rules, and what research gaps remain (e.g., value–stability frontier, CVaR/peak-cash objectives, liquidity floors, counter-cyclical caps)?

Table 1: Summary of data sources and search strategy

Database	Search Field	Keyword (Query)
Scopus	Title, Abstract, Keywords	(“oil and gas” OR petroleum OR upstream OR midstream) AND (infrastructure OR “field development” OR pipeline OR LNG OR FLNG OR refinery OR “gas processing” OR “gas monetization” OR “gas hub”) AND (invest* OR “capital allocation” OR “capital rationing” OR “project portfolio” OR “project selection” OR “infrastructure planning” OR “project sequencing” OR schedul*) AND (uncertaint* OR risk OR budget* OR “cash flow” OR “financial constraint*” OR reserve* OR “resource uncertaint*” OR “production uncertaint*”) AND (optim* OR “decision analysis” OR “operations research” OR “mathematical programming” OR “stochastic” OR robust OR “scenario analysis”)

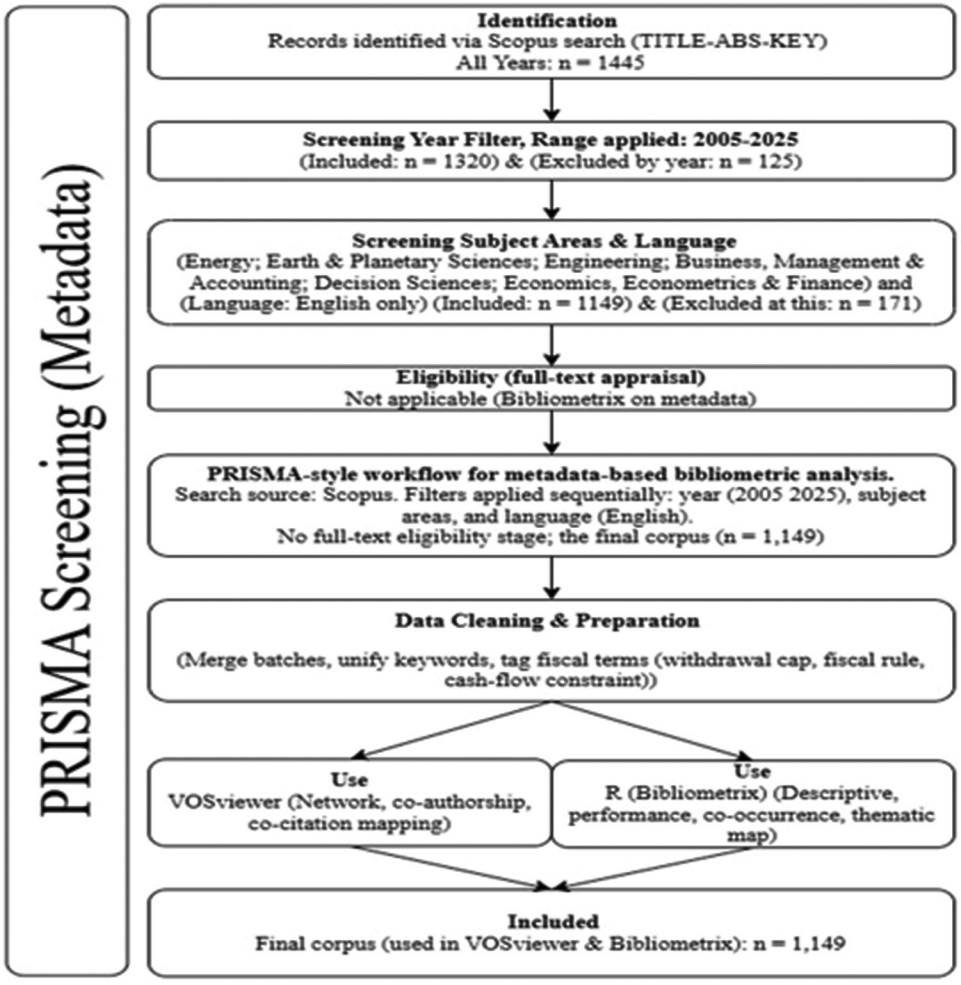
2. METHODS

Table 1 outlines the corpus-extraction process from Scopus inside the TITLE–ABS–KEY domain. Scopus was queried in the TITLE–ABS–KEY field and all records were exported on October 27, 2025. Scopus was chosen due to its extensive interdisciplinary coverage in energy economics and policy, engineering and operations research, and oil and gas, as well as its dependable citation and metadata quality (Mongeon and Paul-Hus, 2016). In total, the PRISMA-style screening proceeded as follows: 1,445 records identified across all years 1,320 after applying the 2005-2025-year filter 1,149 after subject-area and English-language filters. Core keywords were compiled to encapsulate uncertainty-aware optimization in upstream gas infrastructure: domain components (oil and gas, pipeline, LNG/FLNG, gas processing/hub, field development) were integrated with decision components (investment/portfolio/selection/sequencing/scheduling/capacity expansion) and methodological branches (optimization, decision/operations research, mathematical programming, stochastic/robust methods, scenario analysis). The fiscal parameters (capital rationing, budget/cash-flow limitations, fiscal regulations, withdrawal restrictions) were subsequently used during title-abstract screening and metadata filtering to find studies that explicitly analyse multi-period liquidity constraints, a significant issue for energy-finance strategy.

The initial dataset, as indicated by the files, comprised 1,129 records spanning the years 2005-2025. The precision of the query indicators is reflected in the frequency of terms found in the Title/Abstract/Keywords: portfolio/sequence/schedule ≈ 367 documents; stochastic/robust ≈ 340; LNG/pipeline/FLNG ≈ 323; real options ≈ 24; capacity expansion/infrastructure planning ≈ 17; and fiscal terms such as budget/capital rationing/cash-flow constraint/fiscal rule/withdrawal cap ≈ 56 documents (derived from CSV). Following the application of methodological and thematic filtering, which involved the exclusion of non-relevant, duplicate, and non-article format items, as well as any non-English records, the final compilation was established as the SLR dataset for analysis using Bibliometrix/Biblioshiny.

The bibliometric approach was selected due to its efficacy in delineating interdisciplinary and fragmented research domains, uncovering theme/cluster structures, and evaluating the evolution of topics and collaboration (Zupic and Čater, 2015; Donthu et al., 2021). The emphasis on optimizing portfolios within the framework of fiscal regulations is significant, as revenues from oil and gas, along with the governance of sovereign wealth funds, can enhance fiscal stability and promote long-term development (Bagnall and Truman, 2013). Every stage adheres to the PRISMA

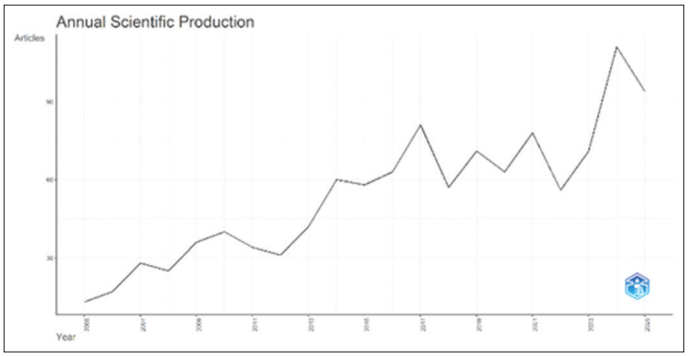
Figure 1: PRISMA screening flow (metadata-based)



protocol to guarantee transparency and the ability to replicate findings (Moher et al., 2009).

Figure 1 delineates the PRISMA-based screening procedure. Scopus was queried in the TITLE–ABS–KEY field, and all metadata were exported on October 27, 2025, yielding 1,445 records across all years. The initial screening phase utilized the 2005-2025-year filter, resulting in 1,320 inclusions and 125 exclusions based on the year. The second stage of screening included subject-area filters Energy; Earth and Planetary Sciences; Engineering; Business, Management and Accounting; Decision Sciences; Economics, Econometrics and Finance and restricted to English-language sources, yielding 1,149 entries (171 were eliminated at this stage). A comprehensive eligibility stage was not implemented as this is a metadata-driven bibliometric study adhering to PRISMA guidelines to guarantee transparency and reproducibility in search and screening (Moher et al., 2009). The dataset was further cleansed and organized by combining batches, standardizing keywords, and annotating fiscal terms: withdrawal cap, fiscal rule, cash-flow constraint. The final corpus (n = 1,149) was examined utilizing VOSviewer for network mapping (co-authorship, co-citation, co-occurrence) and Bibliometrix (r) for descriptive and performance analytics, co-occurrence, and theme mapping. Scopus was chosen for its extensive interdisciplinary coverage and dependable metadata, essential for energy-policy subjects encompassing engineering, economics, and decision sciences (Mongeon and Paul-Hus, 2016). PRISMA offers an auditable and reproducible reporting framework, even for workflows that include simply metadata (Moher et al., 2009). VOSviewer effectively elucidates the conceptual framework of the area via network visualizations (Van Eck and Waltman, 2010), whilst Bibliometrix facilitates reproducible science mapping in accordance with current bibliometric standards (Aria and Cuccurullo, 2017; Donthu et al., 2021; Zupic and Čater, 2015). The complete query strings are included in the Appendix.

Figure 2: Annual publication output and citation dynamics (2005-2025)



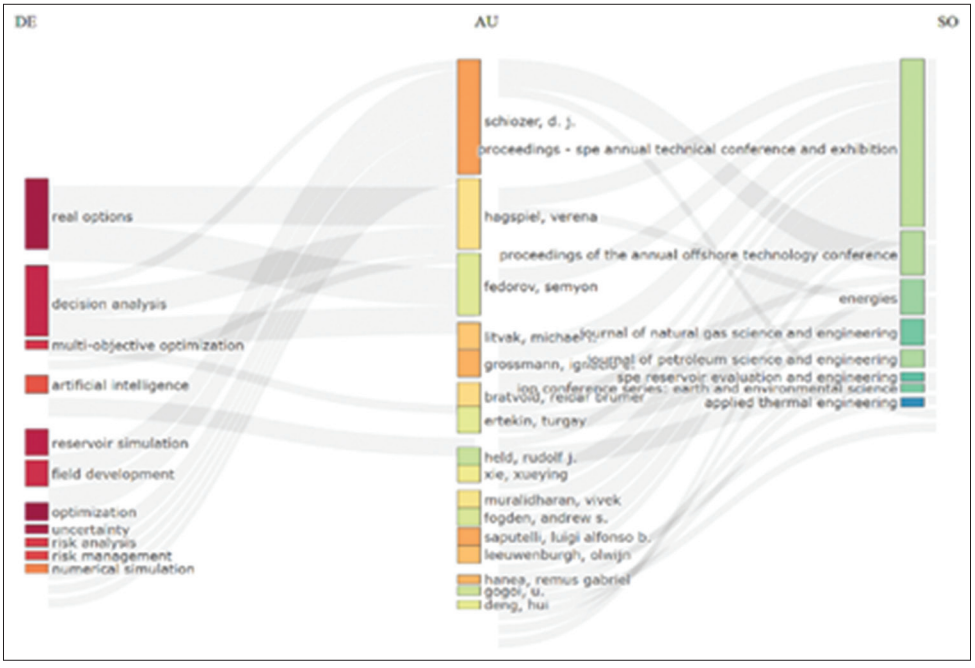
3. RESULTS AND DISCUSSION

3.1. Publications Trends and Research Growth

Figure 2 illustrates a substantial increase in articles regarding portfolio optimization for upstream gas within the context of fiscal regulations and uncertainty from 2005 to 2025. During the initial phase (2005-2012), production progressively escalated from 13 articles in 2005 to a range of 31-42 articles, signifying the preliminary implementation of optimization and stochastic planning for field development, pipelines, and LNG. The period from 2013 to 2017 exhibited a notable increase, culminating in 81 articles in 2017, reflecting an increasing interest in portfolio and scheduling decisions amidst pricing and production uncertainties. Following consistent oscillations from 2018 to 2023 (about 57-78 pieces annually), the literature reached its zenith in 2024 with 111 articles. The 2025 figure (94) is lower due to the ongoing nature of the year (cut-off), hence it does not yet represent the final yearly total.

This trend signifies a concentration of research integrating

Figure 3: Three-field plot (Authors – Keywords – Sources), 2005-2025



portfolio/sequence decisions, stochastic/robust programming, and economic evaluation for upstream gas infrastructure. Currently, keyword tagging within the corpus indicates that the modelling of fiscal and capital regulations remains comparatively infrequent, in contrast to method and domain components, underscoring the significance of this study in bridging the disparity between the precision of decision models and the fiscal policy requirements of the energy sector.

3.2. Intellectual Networks and Thematic Structures

Figure 3 illustrates the triadic relationship among the author keywords (DE) on the left, the author (AU) in the center, and the journal/source (SO) on the right. The principal subjects in the DE domain include real options, decision analysis, and multi-objective optimization, alongside technology clusters such as artificial intelligence, reservoir modeling, field development, optimization, uncertainty, risk analysis/management, and numerical simulation. The discourse surrounding these keywords centers on several prominent authors, including Schiozer, D. J., Hagspiel, Verena, Fedorov, Semyon, Litvak, Michael, Grossmann, Ignacio E., Bratvold, Reidar Brumer, and Ertekin, Turgay, who act as pivotal links between the optimization/decision analysis methodology and the implementation of FDP–reservoir simulation AI applications.

The author indicates that the focus predominantly shifts towards technical-energy channels. Proceedings – SPE Annual Technical Conference and Exhibition, Proceedings of the Annual Offshore Technology Conference, Journal of Petroleum Science and Engineering, Energies, Journal of Natural Gas Science and Engineering, SPE Reservoir Evaluation and Engineering, IOP Conference Series: Earth and Environmental Science, and Applied Thermal Engineering. This setup verifies that the corpus is centered on engineering and operations research, emphasizing technological and market uncertainty as well as decision-making, including optimization, multi-objective analysis, and actual alternatives. Consistent with prior research, fiscal-related nodes/keywords (capital rationing, fiscal restrictions, cash-flow limits) do not serve as significant linkages in this network, suggesting an opportunity to enhance the economic-policy aspect of the oil and gas portfolio optimization literature.

3.3. Co-occurrence and Co-authorship Networks

Figure 4 shows four large interconnected clusters. The green cluster emphasizes oil field development, petroleum reservoir assessment, infill drilling, and horizontal wells, which serve as the practical foundation for reservoir design and characterization. The red cluster encompasses investments, optimization, uncertainty analysis, decision theory, stochastic programming, and real options, which constitute the methodological foundation for portfolio decisions and scheduling (refer to Tarhan et al., 2009; Gupta and Grossmann, 2014; 2017; Bakker et al., 2021; Beck and Bickel, 2022). The blue cluster emphasizes risk management, costs, and the gas industry, linking the economic-risk dimension with industry practice. Finally, the yellow nodes (e.g., enhanced recovery, water injection) bridge production engineering issues with economic evaluation.

Figure 4: Thematic co-occurrence network (author keywords), 2005-2025

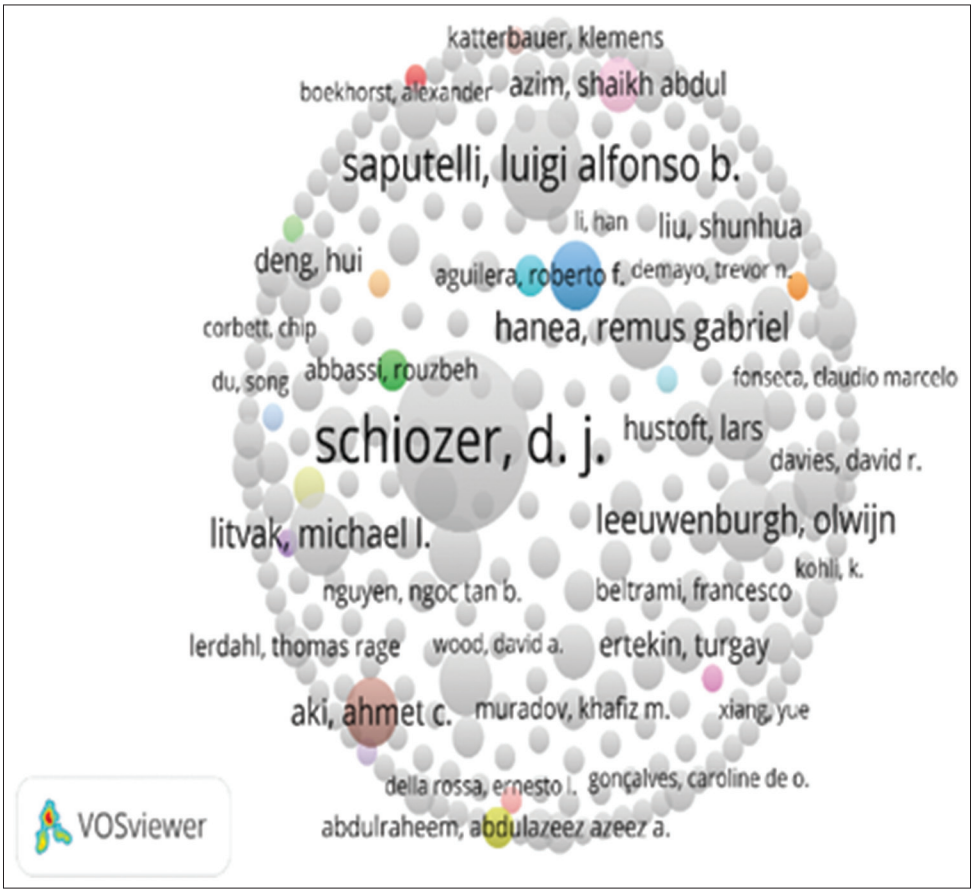


Figure 5: Co-authorship network (authors), 2005-2025

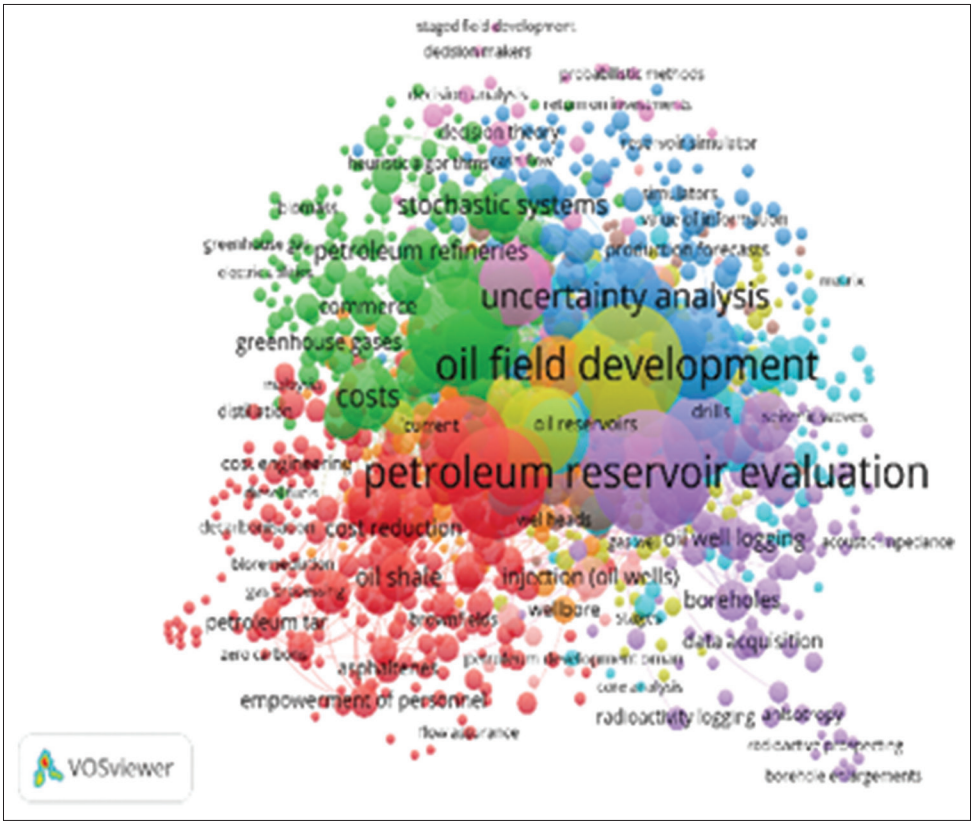
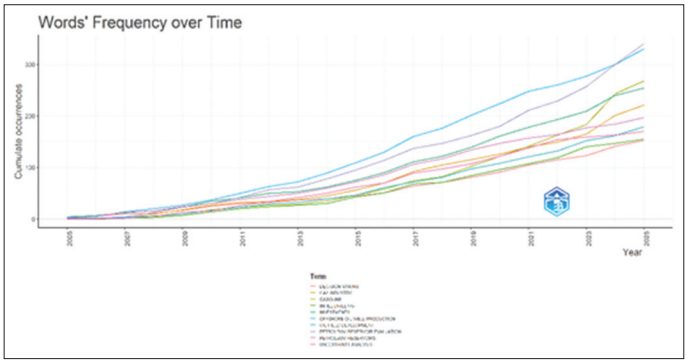


Figure 6: Keyword evolution overlay map (2005-2025)



The map substantiates that the intellectual foundation of this domain is predicated on stochastic optimization and real options for investment decision-making amid uncertainty (e.g., Tarhan et al., 2009; Gupta and Grossmann, 2014), subsequently augmented by research on time options and project flexibility (e.g., Bakker et al., 2021; Beck and Bickel, 2022; Noshchenko and Hagspiel, 2024). Fiscal-themed nodes (e.g., fiscal rules, capital rationing, cash-flow constraints) infrequently manifest as binding nodes, suggesting that the incorporation of fiscal rules into the decision-making framework is constrained—a deficiency that this review addresses (Gupta and Grossmann, 2017, for a framework that incorporates explicit financial considerations).

Figure 5 illustrates that the co-authors network exhibits a somewhat fragmented collaborative structure, featuring several prominent nodes that function as hubs and bridges. Schiozer, D. J. is identified as a prominent node with a significant degree, whereas Grossmann, Ignacio E. is recognized as a methodological anchor frequently associated with optimization and stochastic planning research (Gupta and Grossmann, 2014; 2017). Bratvold, Reidar Brumer serves as a conduit between the decision analysis/real options community and industrial applications; Litvak, Michael and Saputelli, Luigi Alfonso exhibit robust affiliations with the SPE/OTC corridor; Abdulkarim, Anar and Aki, Ahmet C. embody the applied sub-cluster. The network density suggests that cross-group collaboration is present but not yet firmly established, aligning with the thematic observation that policy economics (e.g., fiscal regulations) are not yet thoroughly incorporated into the mainstream optimization and engineering community.

3.4. Evolution of Keywords and Thematic Transitions (2005-2025); Fiscal Regulations and Capital Allocation

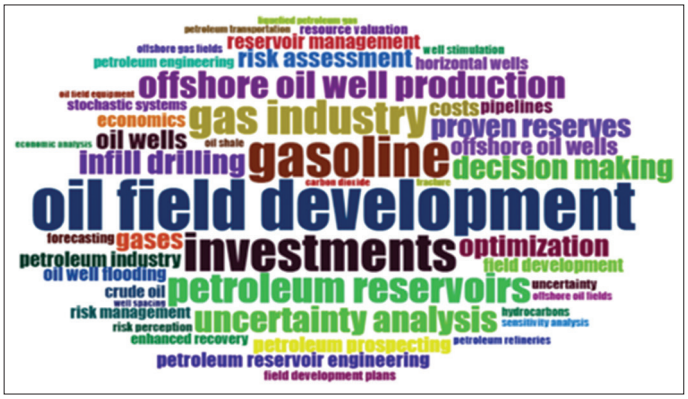
Figure 6 illustrates the cumulative dynamics of the most prevalent keywords within the corpus: oil field development, petroleum reservoir evaluation, offshore oil well production, investments, decision-making, uncertainty analysis, gas industry, gasoline, and infill drilling. The overall trend indicates consistent rise since 2005, with a significant inflection point occurring between 2014 and 2017, during which the majority of the curves exhibited a sharper ascent. The trajectories of oil field development and petroleum reservoir appraisal remain important themes in upstream planning (FDP and reservoir characterisation) until 2025, consistently accruing bibliographic citations throughout time.

Methodologically, uncertainty analysis, decision-making, and investment curves have consistently risen, indicating an

enhanced emphasis on investment decision-making among uncertainty. The strong rise post-2016 aligns with the extensive implementation of optimization, stochastic, and real options frameworks in sequential upstream project portfolio decision-making. Simultaneously, phrases like offshore oil well production, infill drilling, and gas industry serve as a nexus between the technical facets of operations and the economic assessment of projects.

Equally significant, there is an absence of fiscal phrases (e.g., fiscal regulations, capital restrictions, cash-flow limitations) in the compilation of predominant keywords. This absence highlights a conceptual deficiency: the literature has significantly developed technical underpinnings and decision-making methodologies, however seldom incorporates fiscal rules and multi-period financial limitations directly. This discovery corresponds with the article's aim of optimizing portfolios for upstream gas within the context of fiscal regulations and uncertainty, synthesizing current research while introducing a fiscal framework to contemporary portfolio and scheduling models, thereby enabling a more operational assessment of policy indicators (ENPV, risk/CVaR, and break-even time).

Figure 7: Tree map of dominant keywords (2005-2025)



3.5. Thematic Concentrations from Tree Map and Word Cloud

Figure 7 illustrates the relative frequency of keywords within the corpus. The predominant block comprises technical-domain themes: petroleum reservoir assessment and oil field development, followed by gasoline, investments, gas industry, petroleum reservoirs, and offshore oil well production. Encircling this core are clusters of decision-making methodologies, optimization techniques, uncertainty analysis, and risk assessment/management, as well as stochastic systems, which demonstrate a pronounced focus on optimization and risk assessment in field development and well operations. Although economic terminology (economics, costs, resource valuation, economic analysis) is evident, its representation is comparatively limited, suggesting that the policy/funding aspect has not yet emerged as a significant constraint within the keyword network. This map substantiates a thematic framework focused on FDP/reservoir characterization, accompanied by a layer of decision-making as a methodological adjunct.

Figure 8 corroborates the tree map's findings by emphasizing the most prevalent words. The phrase "oil field development" is the most prominent, succeeded by "petroleum reservoirs," "uncertainty analysis," "investments," "gas industry/gasoline," and "offshore oil well production." The terms "decision making" and "optimization" suggest that portfolio/scheduling analyses and economic assessments have been assimilated into technical dialogue. Nevertheless, terms denoting fiscal regulations and liquidity limitations (e.g., fiscal rules, capital rationing, cash-flow constraints) are not prominently featured in the word cloud, aligning with prior findings that fiscal overlays are infrequently articulated in decision models; this study addresses that gap.

3.6. SLR Evidence on Upstream Gas Portfolio Optimization under Fiscal Rules

This systematic literature review enhances the bibliometric findings by synthesizing research on the optimization of upstream

Figure 8: Word cloud of core topics (2005-2025)

Table 2: Findings from the systematic literature review on portfolio optimization for upstream gas considering fiscal regulations and uncertainty

Theme/Cluster	Key evidence and methods	Policy implications/research agenda
Planning infrastructure in the field amidst uncertainty	Multistage stochastic programming for facility design and production scheduling, incorporating uncertain prices and production yields (Tarhan et al., 2009; Gupta and Grossmann, 2014).	Comparing stochastic and deterministic models for sequencing; prepared for integration with fiscal and cash-flow constraints.
Portfolio management and scheduling with a focus on financial implications	Stochastic optimization combined with explicit financial considerations (Gupta and Grossmann, 2017).	Preliminary findings indicate that financial limitations influence the selection and timing of projects; this necessitates the establishment of more rigorous fiscal regulations and the formulation of withdrawal caps.
Investment timing and flexibility	Real options related to oil and gas assets include strategies such as defer, expand, abandon, and invest-or-exit (Bakker *et al*., 2021; Beck and Bickel, 2022).	In volatile markets, the importance of flexibility cannot be overstated; however, the combination of real options with budgeted portfolios remains uncommon.
Multi-objective real options	Real options with economic–environmental objectives (Noshchenko and Hagspiel, 2024).	Offers insights into policy boundaries; can be enhanced with risk metrics (CVaR) and fiscal limitations.
Monetization and capacity expansion routes	Optimization/decision analysis for LNG versus pipeline and capacity expansion (corpus synthesis).	Route/capacity decisions are models, but fiscal rules/ capital rationing are rarely made explicit→major gap.

gas investments under the constraints of fiscal regulations on annual cash flows. The corpus identifies two primary foundations: stochastic/robust optimization for portfolio sequencing and real options for temporal/scalable flexibility. Additionally, it finds that incorporating multi-period liquidity constraints significantly alters project selection and cash flow profiles compared to models that disregard fiscal constraints. Significant gaps persist: fiscal regulations (e.g., withdrawal limits, capital constraints) are seldom clearly articulated; hence, Table 2 delineates the presence and absence of fiscal overlays, forming the foundation for our proposed integrative framework.

Table 2 outlines five analytical pathways for addressing oil and gas investments in the context of budget limitations imposed by withdrawal caps. In the context of less developed approaches, hard caps without stochastic planning refer to the implementation of fixed withdrawal limits alongside a deterministic assessment of projects based on a singular net present value. This approach often promotes front-loading in periods of growth, reductions during downturns, significant peak cash flows, and unpredictable fiscal fluctuations. Advancing further, caps and staging heuristics provide enhancements in project staging to facilitate cash flow management; however, they currently lack integration of risk metrics such as CVaR or peak cash minimization, along with stochastic scenarios. Consequently, the portfolio's value and its resilience to shocks are still constrained.

On the more mature side, designed caps and robust–stochastic optimization reflects multi-period cap designs (e.g., with liquidity floors, counter-cyclical rules) that are then internalized into a stochastic/robust optimization model with dual objectives: maximizing ENPV while controlling downside risk and peak cash under precedence and execution capacity constraints. This configuration typically leads to a sequencing that prioritizes enablers, accelerates the time to break even, and enhances fiscal resilience. The latter two pathways highlight the importance of implementation context: gas-centric and modular portfolios under caps promote the selection of gas portfolios (pipelines, LNG, energy hubs) with a modular architecture designed to stabilize cash profiles and maintain options for trigger-based acceleration or deferral. Additionally, aligning policy analytics suggests that incorporating caps as multi-period liquidity constraints within the model, alongside risk control objectives, leads to a project sequence that is more resilient to various scenarios compared to traditional NPV ranking. This approach also creates opportunities for hedging strategies and diverse financing mixes to mitigate downside risk.

3.7. Policy and Research Implications

Table 3 presents a concise overview of the policy implications and essential research agenda derived from this review. The synthesis and bibliometric analysis indicate that the success of upstream gas investments in uncertain conditions is influenced not only by geological quality but also by the design of fiscal rules, adherence to multi-period cash flow discipline, and the incorporation of risk optimization frameworks in portfolio planning. Cross-cluster findings highlight the necessity of incorporating withdrawal caps into decision-making frameworks, utilizing risk metrics (such as CVaR/peak cash) in conjunction with ENPV, and enhancing project flexibility (through real options and modularization) to ensure that investment recommendations are consistent with fiscal stability and energy transition objectives.

Table 3 delineates nine complementary domains of research policy. Initially, empirical research in fiscal rule design indicates that inflexible hard caps often lead to front-loading in periods of economic expansion and significant reductions during downturns. Consequently, a more credible policy alternative involves multi-period caps with liquidity floors/buffers and countercyclical components that can be routinely evaluated through production price scenario stress testing to preserve fiscal flexibility while upholding discipline.

Secondly, incorporating caps into portfolio models is a methodological must. Numerous portfolio optimization models continue to regard the budget as a collective restriction; however,

Table 3: Implications for policy and analysis in upstream gas portfolio optimization considering fiscal regulations and uncertainty

Area	Key insights	Implications
Fiscal rules design	Strict hard caps often lead to front-loading in periods of growth and reductions during downturns; caps designed for multiple periods (such as liquidity floors and countercyclical rules) help to stabilize cash flows.	Establish withdrawal limits based on design cycles, incorporating liquidity thresholds and buffers; perform yearly fiscal stress assessments under various price and production conditions.
Integration of caps into the portfolio model	Most optimization studies fail to account for multi-period liquidity limitations; when incorporated, project selection and sequencing undergo substantial alterations.	Mandate cash-flow limitations for each period in MILP/stochastic models; present ENPV alongside fiscal indicators (maximum cash, time to break-even).
Risk metrics (downside control)	ENPV alone is not sufficient in volatile environments; CVaR/peak-cash minimization reduces tail losses.	Incorporate secondary objectives: minimize Conditional Value at Risk (CVaR) or minimize peak cash; employ portfolio risk restrictions to uphold fiscal discipline.
Flexibility and real options	Defer/expand/abandon improves the value and resilience of the investment schedule.	Incorporate real options as decision variables into the portfolio model; establish operational triggers (price, reserves) and implement evidence-based execution protocols.
Monetization and capacity expansion routes	The decision between LNG and pipelines and capacity expansion affects cash flow and market risk profiles.	Perform collaborative assessments of route capacity and fiscal factors; employ multi-period capacity limitations and demand/price elasticity analysis.
Modular project architecture	Modularization (phasing, tie-back, fast-track) evens out cash flow and facilitates adaptation to caps.	Prioritize the modular gas portfolio (pipeline/LNG/hub) and facilitators initially to expedite break-even and stabilize cash flow.
Data and uncertainty	Project value is sensitive to uncertainty in prices, reserves, and production rates.	Employ multistage stochastic programming with calibrated scenarios; conduct value of information analysis for survey and measurement decisions.
Funding and hedging	A combination of financing/hedging instruments can reduce fiscal downside.	Align funding strategies (project financing, sovereign wealth fund withdrawals) with the portfolio timeline; assess hedging in relation to fiscal risk objectives.

when cash-flow limitations are incorporated on a per-period basis, the arrangement and timing of projects exhibit substantial alterations. Consequently, the presentation of results must align ENPV with financial measures, including peak cash and time-to-break-even, to facilitate the implementation of suggestions.

Third, in risk management, dependence on a singular ENPV is inadequate in a turbulent context. Incorporating secondary objectives, such as lowering CVaR or peak cash, mitigates tail losses and upholds cash flow discipline. Fourth, flexibility and real options such as defer, enlarge, or abandon have demonstrated an enhancement in the value and robustness of investment schedules; their implementation must be defined as decisions inside portfolio models with explicit operational triggers (price/reserves).

Fifth, the monetization and capacity expansion options (LNG versus pipeline; capacity growth) must be assessed concurrently with fiscal limitations, as they substantially influence cash flow profiles and market risk. Utilizing multi-period capacity restrictions and conducting demand/price sensitivity analysis constitutes optimal practice. Sixth, modular project architecture utilizing phasing, tie-backs, or fast-track enablers enhances cash flow and allows for modifications to caps; strategically, an enablers-first approach expedites break-even.

Seventh, regarding data and uncertainty, the project's value is significantly affected by fluctuations in prices, reserves, and production rates; thus, multistage stochastic programming with calibrated scenarios and assessment of the value of information for survey and measurement decisions are essential measures. The alignment of financing and hedging with the portfolio plan is essential: a strategic combination of project finance, sovereign wealth fund withdrawals, and commodity hedging can mitigate fiscal risks, contingent upon adherence to predetermined risk targets.

Ultimately, openness and reporting must extend beyond NPV to encompass policy dashboards that incorporate ENPV, CVaR, peak cash, debt service, and buffers, while also illustrating the policy frontier (value versus stability). The primary gap in the research agenda is to create a stochastic-real-options framework that incorporates fiscal regulations as multi-period liquidity constraints, then evaluating it against traditional NPV rankings in case studies of countries or real assets. This methodology facilitates investment recommendations that are concurrently useful, risk-managed, and aligned with budgetary prudence.

4. LIMITATIONS AND FUTURE RESEARCH

4.1. Limitations

The data scope is confined to Scopus and English-language records from 2005 to 2025, which may introduce coverage bias against non-English research or pertinent local publications. The bibliometric approach, encompassing co-occurrence and citation networks, is contingent upon keyword selection, frequency thresholds, and mapping parameters; outcomes may vary with the use of alternative criteria or algorithms. This review did not perform a quantitative meta-analysis of the economic consequences or a systematic full-text coding of all papers; thus, the conclusions are thematic syntheses rather than effect

estimations. The evidence from systematic literature reviews regarding fiscal rule overlays is predominantly theoretical or derived from specific case studies; so, generalizations across countries should be approached with caution. Fifth, we did not implement new numerical models utilizing country-specific data; empirical policy evaluations (e.g., the policy frontier of value vs stability) have not been validated against actual budgetary data.

4.2. Future Research

Key areas for future research encompass:

1. The formulation of a comprehensive stochastic-real options framework with a multi-period fiscal rule overlay (withdrawal caps, liquidity floors) integrated as annual cash flow limitations and risk objectives (CVaR/peak-cash).
2. Empirical testing based on country or asset data utilizing actual cash flow and policy information to evaluate sequencing variations in comparison to the classical NPV baseline and to delineate the policy frontier (value versus stability).
3. Creation of an open dataset categorizing fiscal keywords (fiscal laws, capital rationing, cash-flow limits) to mitigate annotation bias in future bibliometric analyses.
4. Fiscal design experiments (hard caps versus countercyclical designed caps, liquidity floor dimensions) and financing/hedging tools, associated with break-even timing and fiscal risk profiles.
5. Advanced methodologies: distributionally resilient optimization, SDDP/Benders for multistage problems, and metaheuristics (relax–optimize–fix) for extensive portfolios with multi-period capacity restrictions.
6. Objective extensions: integrating ESG/environmental considerations and externalities into multi-objective functions to enhance relevance for energy transition.
7. Macro–micro linkages: integrating project portfolio models with macro fiscal models (e.g., revenue volatility, sovereign wealth fund withdrawal limits) to evaluate spillovers to fiscal stability.

5. CONCLUSION

This study integrates a PRISMA-compliant systematic review with bibliometric mapping to elucidate the optimization of upstream gas portfolio decisions under the constraints of fiscal regulations on annual cash flows. Evidence indicates a unified intellectual foundation for stochastic and resilient optimization concerning sequencing and genuine possibilities for timing and size. Publication trends from 2005 to 2025 demonstrate consistent increase; network analysis and keyword progression reveal the prevalence of analytical-decision and reservoir planning topics, however financial constraints (e.g., withdrawal limitations, cash flow/budget restrictions) are inadequately reflected in conventional models. SLR synthesis demonstrates that the explicit incorporation of multi-period liquidity constraints modifies project selection, sequencing, peak cash requirements, and break-even timing in contrast to a baseline devoid of such constraints.

We advocate transitioning from rigid caps to multi-period caps that incorporate liquidity floors and countercyclical components, which are directly embedded in the optimization model. The portfolio must integrate a gas-centric modular framework (pipeline/LNG/hub) with objectives for downside risk management (e.g., reduction of CVaR or peak cash) in conjunction with ENPV, to attain equilibrium between value generation and financial stability. The primary research gap is the lack of a cohesive stochastic-real options framework that incorporates fiscal rules to jointly optimize sequencing and capacity development while delineating the policy frontier (value versus stability). Bridging this gap will synchronize analytical precision with public finance standards and yield additional practical advice for governments and National Oil Companies in the context of fluctuating prices and stringent budgetary constraints. Section 4 delineates the study's shortcomings and proposes avenues for future research to facilitate replication and methodological advancement.

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