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Supplier Diversification Under Geopolitical Uncertainty: A Decision Model for Resilient Oil Procurement

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Abstract

Geopolitical shocks in 2025 showed how quickly a low-cost crude source can become unavailable or expensive to deliver. The Israel and Iran confrontation threatened traffic through the Strait of Hormuz and pushed freight and war-risk premiums sharply higher, renewed Houthi attacks in the Red Sea revived Cape of Good Hope diversions, and naval drone strikes interrupted loadings at the CPC terminal near Novorossiysk. These events were route-specific and partly correlated, and they arrived in a year of soft benchmark prices, when procurement decisions guided by delivered price alone appeared safe. This paper develops a decision model that helps refiners and national oil companies decide not only which suppliers to buy from but how much to take from each, comparing alternatives on four criteria: purchase cost, transport risk, lead time and supply security. The model has three linked stages. The Analytic Hierarchy Process (AHP) converts the priorities of a procurement committee into consistent criteria weights; TOPSIS ranks candidate suppliers and assigns them to strategic, flexible and opportunistic tiers that guide contract type; and a scenario-based mean and Conditional Value-at-Risk (CVaR) linear programme allocates monthly volume subject to supplier caps, chokepoint exposure limits, a lead-time ceiling and a minimum portfolio supply-security score. Lead time is priced through in-transit carrying cost and late-arrival penalties, and disruptions are generated with a Gaussian copula so that Middle East and Black Sea outages can occur together and coincide with spikes in replacement prices. The model is applied to a stylised western Mediterranean refinery buying 6.0 million barrels per month from eight origins and is stress tested under five regimes calibrated to 2025 events. Norway, the United States and Brazil rank highest, yet the optimal portfolio (United States 30%, Kazakhstan 20%, Brazil 20%, Norway 15% and Libya 15%) also takes capped volumes of discounted, lower-ranked crude, showing that rankings and allocations answer different questions. The recommended portfolio costs only USD 0.07 per barrel more in expectation than a pure cost minimiser, removes Hormuz exposure and raises the portfolio security score to 7.50. Under compound stress it lowers the 95% CVaR of delivered cost by USD 4.47 per barrel, about USD 26.8 million in a severe month, while single sourcing reaches a tail cost of USD 89.46 per barrel. Re-optimising once a regime shift is recognised reduces compound-stress CVaR further, from USD 77.13 to USD 75.89 per barrel, and sensitivity analysis shows that most of the protection comes from the security floor and chokepoint caps rather than from the risk-aversion parameter. The results indicate that resilience is inexpensive when it is bought through explicit, auditable constraints, that supplier rankings are better used to set contract tiers than volumes, and that pre-agreed rebalancing triggers offer practical protection for procurement desks. The framework is transparent and solvable with standard tools, although its inputs are illustrative and should be replaced with firm-specific data before use.

Keywords: Oil Procurement, Supplier Diversification, Geopolitical Risk, AHP, TOPSIS, Conditional Value-at-Risk, Stochastic Programming, Energy Security, Supply Chain Resilience

1. Introduction

Oil importers face a procurement problem that looks simple on a price screen and is complex in practice. Benchmark prices were relatively soft through 2025: the U.S. Energy Information Administration (EIA) reported that Brent averaged about USD 69 per barrel for the year, with monthly averages falling from roughly USD 79 in January to around USD 63 by December (EIA, 2025a; EIA, 2025b). A buyer guided only by delivered price would therefore have had little reason to worry about supply. Yet the same year produced a dense sequence of geopolitical shocks that affected specific routes and specific origins rather than the market as a whole.

In June 2025 the military confrontation between Israel and Iran pushed tanker freight rates sharply higher and reduced transits

through the Strait of Hormuz, even though the strait itself was never closed (S&P Global, 2025). In July, Houthi forces resumed attacks on merchant shipping and sank the bulk carriers Magic Seas and Eternity C, reviving war-risk premiums and Cape of Good Hope diversions for Red Sea traffic (Bloomberg, 2025). In late November, Ukrainian naval drones damaged a single point mooring at the Caspian Pipeline Consortium (CPC) terminal near Novorossiysk, interrupting loadings of Kazakh CPC Blend, a crude that many Mediterranean refiners had treated as a reliable workhorse grade (Marine Insight, 2025). These events share a feature that matters for procurement: they raise the cost and the risk of particular supply lines, and they can arrive together.

The question that follows is practical. Given a set of alternative suppliers that differ in purchase cost, transport risk, lead time and supply security, how should a buyer allocate volumes so that the portfolio is economical in normal months and survivable in bad ones? Two literatures speak to this. Multi-criteria supplier selection methods such as AHP and TOPSIS are widely used to rank suppliers on several attributes (Ho *et al*., 2010), but they rank rather than allocate and they do not represent correlated, low-probability disruptions. Stochastic programming and risk measures such as CVaR (Rockafellar and Uryasev, 2000) handle tail risk and allocation, but on their own they say little about qualitative criteria such as political stability or contract reliability. Recent work on procurement in oil and gas settings has stressed strategic sourcing optimisation, risk management models and resilience frameworks for critical facilities (Okonkwo *et al*., 2018a; Agbabiaka *et al*., 2019; Ogunwole *et al*., 2021), yet these frameworks are largely conceptual and stop short of a quantitative rule for splitting volume across suppliers.

This paper integrates the two into a single decision model and applies it to a stylised 2025 procurement problem. Its contributions are threefold. First, it defines a compact, auditable set of indicators for the four criteria named in the research focus, including a lead-time cost that converts days at sea into dollars through inventory carrying and late-arrival penalties. Second, it links an AHP-weighted TOPSIS screen to a mean and CVaR allocation model with a portfolio supply-security floor, chokepoint caps and a lead-time ceiling, so that qualitative judgement and quantitative tail risk are both represented. Third, it stress tests the resulting portfolios under regimes calibrated to the Hormuz, Red Sea and Black Sea events of 2025 and derives procurement rules that can be used in monthly planning.

The remainder of the paper is organised as follows. Section 2 synthesises the related literature and the 2025 risk landscape. Section 3 presents the conceptual model, and Section 4 sets out the methodology. Section 5 reports the numerical results and Section 6 discusses them. Sections 7, 8 and 9 present the implications, limitations and directions for future research, and Section 10 concludes.

2. Literature Synthesis

The decision problem in this paper sits where several literatures meet: energy security and import diversification, the economics of oil supply shocks and geopolitical risk, maritime transport risk, multi-criteria supplier evaluation, supplier diversification under disruption, supply chain resilience, and optimisation under uncertainty. A growing body of applied work on procurement, digital supply chains, decision analytics and critical infrastructure in emerging economies adds practical context. This section reviews each strand in turn and closes with the gap the model is designed to fill.

2.1 Energy security, import diversification and oil supply shocks

Diversification of import sources has long been treated as a core instrument of oil security. Yergin (2006) argued that security lies in variety and flexibility of supply, and the conceptual literature has since debated what exactly is being secured. Early formulations organised the idea around availability, accessibility, affordability and acceptability, while later work stressed that energy security is polysemic and context-dependent and is better defined as the continuity of supply relative to demand or as the protection of vital energy systems from disruption (Chester, 2010; Winzer, 2012; Cherp and Jewell, 2014). Synthesis frameworks and indicator reviews catalogue a large number of metrics across availability, affordability, technology, sustainability and governance dimensions (Sovacool and Mukherjee, 2011; Ang *et al*., 2015; Gasser, 2020), building on earlier indicator families for long-term supply security (Jansen *et al*., 2004; Kruyt *et al*., 2009).

For oil importers, the most widely used indicators are concentration measures. Cohen *et al*. (2011) track Herfindahl-Hirschman based diversification of oil and natural gas supplies across countries, and later indices weight each supplier by its political risk (Le Coq and Paltseva, 2009; Lefèvre, 2010) or by country risk and potential exports (Yang *et al*., 2014). Composite vulnerability indices combine import dependence, supplier concentration, price exposure and economic resilience (Gupta, 2008; Henriques *et al*., 2024), and the oil security premium literature shows that the welfare cost of disruption depends on whether imports come from stable or unstable suppliers (Brown and Huntington, 2013). Vivoda (2009) cautioned, however, that diversification is not an end in itself: shifting volumes toward many small but unstable suppliers can lower concentration while raising exposure. Liadi (2023c) makes a parallel argument from the exporter's side, showing that oil-dependent states also need diversified engagement strategies, while Gideon (2025) evaluates risk mitigation strategies for strategically sensitive supply chains exposed to concentrated sources. The present model reflects these warnings by combining a concentration control with an explicit supply-security floor rather than rewarding diversification for its own sake.

Portfolio theory (Markowitz, 1952), first applied to energy planning for generation mixes (Awerbuch and Berger, 2003), has been extended to national crude import portfolios. Wu *et al*. (2009) compare portfolio-based and index-based measures of import risk, Ge and Fan (2013) add country risk to an improved portfolio approach, and Zhang *et al*. (2013) evaluate import security along the whole supply chain, from producing country through sea lanes to domestic distribution. Related studies quantify the macroeconomic impact of import risk (Sun *et al*., 2014), formulate multi-objective crude supply portfolios under interval forecasts (Sun *et al*., 2022), simulate the resilience of an import system to external shocks with system dynamics (Chen *et al*., 2020), and estimate how geopolitical risk erodes crude oil security (Wang *et al*., 2021; Gong *et al*., 2022). The closest study to the present case is Desogus

et al. (2023), who model geopolitical impacts on the Italian crude oil supply and show that chokepoint exposure and crude-quality constraints limit the benefits of diversification. Strategic stockpiles are the natural complement to diversification, and dynamic programming models of reserve release and delegation date back several decades (Teisberg, 1981; Chen *et al*., 2014). These studies operate at national level and rarely translate risk measures into the monthly volume decisions of an individual refiner, which is the level at which this paper works.

A large empirical literature studies how supply disruptions move oil prices and economic activity. Hamilton (2003) proposed nonlinear measures of oil shocks, and Kilian (2008) quantified exogenous supply shocks caused by wars and revolutions in producing countries. Kilian (2009) showed that supply and demand shocks have very different effects, a result refined by work on inventories and speculative demand (Kilian and Murphy, 2014) and summarised in a review of four decades of oil price fluctuations (Baumeister and Kilian, 2016). Hamilton (2009) traced the 2007-08 price spike and its consequences, Mohaddes and Pesaran (2016) estimated the global effects of country-specific supply disruptions, and Känzig (2021) identified supply news shocks from OPEC announcements. For a buyer, the key message is that disruptions at one origin propagate through the global price, so the replacement barrel is purchased in a market the shock has already tightened.

Geopolitical risk can now be measured with news-based indices (Caldara and Iacoviello, 2022), and these measures have been linked to oil markets over long horizons (Antonakakis *et al*., 2017), to price jumps (Noguera-Santaella, 2016), to volatility (Liu *et al*., 2019), to time-varying price effects (Cunado *et al*., 2020) and to political tensions between producers and consumers (Mignon and Saadaoui, 2024). The Russia and Ukraine war offered a natural experiment: oil co-moved differently with other assets during the conflict (Adekoya *et al*., 2022), commodity volatility rose sharply (Fang and Shao, 2022), the energy price channel accounted for much of the war's economic cost (Liadze *et al*., 2023), and crude prices carried a measurable war premium (Zhang *et al*., 2024). This literature motivates two features of the model: a common geopolitical factor that correlates disruptions across exposed suppliers, and a price spike term that raises the cost of replacement cargoes in bad states.

2.2 Maritime transport risk and chokepoints

Transport risk is a distinct dimension of supplier choice because the same crude can arrive by routes with very different exposure. Tanker freight responds to oil prices and supply shocks (Shi *et al*., 2013; Shi *et al*., 2022), to the supply of vessels (Regli and Nomikos, 2019) and to regional conditions such as those modelled for the Arabian Gulf (Kilian *et al*., 2023), and geopolitical risk spills over from oil into tanker markets and freight rates (Monge *et al*., 2023; Chen *et al*., 2025). Chartering behaviour matched with vessel tracking data shows how contracting lead times adjust to market conditions (Prochazka *et al*., 2019), which is relevant to the lead-time criterion in this paper.

Chokepoints concentrate this risk. Network analyses of the global maritime system show how closure of a strait or canal forces costly rerouting (Alderson *et al*., 2020), and the Red Sea crisis has been examined in detail for its effects on vessel operations, shipping networks and supply chains (Notteboom *et al*., 2024; Haralambides, 2024; Rodriguez-Diaz *et al*., 2024). Route-choice models for crude imports trade off cost against connectivity reliability (Wang *et al*., 2018; Wang *et al*., 2023) or use fuzzy TOPSIS to compare alternative corridors (Ur Rehman and Ali, 2021), and Wang *et al*. (2020) build a stochastic procurement model that jointly considers crude prices, country risk and transportation risk, which is the closest existing formulation to the allocation model here. Piracy adds a further layer of cost through rerouting, insurance and trade diversion (Fu *et al*., 2010; Bensassi and Martinez-Zarzoso, 2012; Besley *et al*., 2015). Port-side logistics matter as well: demurrage is a controllable cost in emerging-economy ports (Okonkwo *et al*., 2020), and customs administration and trade facilitation at ports are increasingly supported by artificial intelligence (Jones and Ominyi, 2024). At the loading end, export terminals, floating storage units, mooring systems and hoses are single points of failure for entire crude streams, which is why their integrity, inspection and offloading operations receive close engineering attention (Obetta and Ninduwezuor-Ehiobu, 2018; Obetta and Ninduwezuor-Ehiobu, 2019; Obetta *et al*., 2020; Obetta *et al*., 2022; Obetta *et al*., 2025).

2.3 Supplier evaluation, diversification and resilience

Supplier evaluation is a classic multi-criteria decision problem. Early surveys identified quality, delivery, price and capability as core criteria (Dickson, 1966; Weber *et al*., 1991), and later reviews document the dominance of AHP, TOPSIS and their hybrids (Ho *et al*., 2010; Chai *et al*., 2013; Govindan *et al*., 2015). AHP structures expert judgement through pairwise comparisons with a consistency check (Saaty, 1980; Saaty, 1990) and has been applied across many domains (Vaidya and Kumar, 2006); TOPSIS ranks alternatives by relative closeness to ideal and anti-ideal solutions (Hwang and Yoon, 1981) and has a similarly broad record (Behzadian *et al*., 2012). Fuzzy variants handle imprecise judgements (Chen *et al*., 2006), and fuzzy extended AHP has been used to develop global suppliers while accounting for risk factors (Chan and Kumar, 2007).

Applied work in emerging economies shows the same reliance on scoring. Data-driven vendor evaluation and bid selection models (Ahiaeke Patrick *et al*., 2021), GIS-enabled ERP procurement (Ahiaeke Patrick *et al*., 2020), supplier relationship management frameworks (Ike *et al*., 2021; Akinleye and Adeyoyin, 2022b; Akin-Oluyomi *et al*., 2024), studies of vendor management practice (Wedraogo *et al*., 2025), business intelligence dashboards for vendor performance (Abdulrazaq *et al*., 2025; Babatope *et al*., 2023), supplier sustainability and risk metrics (Akin-Oluyomi *et al*., 2023c; Akin-Oluyomi *et al*., 2023b), and contract negotiation and vendor governance models (Okonkwo *et al*., 2019; Akinleye and Adeyoyin, 2022a) all score suppliers carefully. What these approaches seldom do is translate the scores into volume shares that account for correlated disruptions, which is the role of the allocation stage in this paper.

A second stream asks how many suppliers to use and how to split orders among them. Decision-analytic models determine the optimal size of the supplier base when suppliers can fail (Berger *et al*., 2004; Ruiz-Torres and Mahmoodi, 2007), and models of single versus dual sourcing show when diversification pays (Yu *et al*., 2009). Tomlin (2006) distinguished mitigation strategies, such as

holding inventory or sourcing from several suppliers, from contingency strategies such as rerouting, a distinction mirrored in the rebalancing triggers proposed later. Sawik (2011) introduced CVaR-based selection of supply portfolios under disruption risk and extended it to resilient portfolios and to joint supplier selection and scheduling (Sawik, 2013; Sawik, 2014); these are the closest methodological ancestors of Stage 3. Torabi *et al*. (2015) combined resilient supplier selection with order allocation under operational and disruption risks, and reviews of operations research models for disruptions and of quantitative resilience methods map the wider field (Snyder *et al*., 2016; Hosseini *et al*., 2019). Practice-oriented frameworks for strategic sourcing and supply shock mitigation (Nwangwu *et al*., 2025), predictive vendor risk assessment and procurement cost optimisation (Tonoyan *et al*., 2024a), procurement risk management in multinational enterprises (Bello *et al*., 2023), comparative procurement cost strategies (Akokodaripon *et al*., 2023) and big-data procurement optimisation (Akinleye *et al*., 2023) point in the same direction but remain largely conceptual.

Resilience is now a mature concept in supply chain management. Foundational contributions define it as the capacity to prepare for, respond to and recover from disruption (Christopher and Peck, 2004; Ponomarov and Holcomb, 2009) and emphasise deliberate redundancy and flexibility (Sheffi, 2005; Tang, 2006; Chopra and Sodhi, 2004). Disruption risk can be managed through specific practices (Kleindorfer and Saad, 2005), the severity of disruptions depends on network design and mitigation capability (Craighead *et al*., 2007), and balancing vulnerabilities against capabilities is central to resilience frameworks (Pettit *et al*., 2010). Systematic reviews consolidate these ideas (Tukamuhabwa *et al*., 2015; Kamalahmadi and Parast, 2016). The financial stakes are large: disruptions are followed by lasting losses in shareholder value (Hendricks and Singhal, 2005), and shocks propagate along supply networks through ripple effects (Dolgui *et al*., 2018), as global simulations of the pandemic illustrated (Ivanov, 2020).

Recent work from emerging economies applies these ideas to distribution networks, post-pandemic supply chains and energy facilities. Reviews of post-disruption resilience (Anene, 2021), composite resilience indices (Efobi *et al*., 2023), resilience frameworks for gas processing plants and critical infrastructure (Ogunwole *et al*., 2021), risk management models for EPC and gas projects (Agbabiaka *et al*., 2019), resilient humanitarian logistics (Anene and Clement, 2022) and sustainable procurement and resilience frameworks for pharmaceutical operations (Akinleye, 2024) all stress redundancy, visibility and response planning. Resilience models for other critical systems exposed to geopolitical risk, such as cross-border payment infrastructure (Adesuyi *et al*., 2025) and post-pandemic financial collaboration (Isiekwu *et al*., 2025), offer transferable principles: redundancy across independent channels and explicit continuity plans.

2.4 Optimisation, procurement practice and decision analytics

On the methodological side, portfolio selection (Markowitz, 1952) gave way to coherent risk measures (Artzner *et al*., 1999) and to CVaR, which captures tail severity and can be optimised by linear programming over scenarios (Rockafellar and Uryasev, 2000; Rockafellar and Uryasev, 2002). CVaR objectives and constraints have been embedded in portfolio problems (Krokhmal *et al*., 2002), and the differences between VaR and CVaR in optimisation are well documented (Sarykalin *et al*., 2008). Stochastic programming provides the general framework for decisions under scenario uncertainty (Shapiro *et al*., 2009; Birge and Louveaux, 2011), with methods for generating scenario trees (Hoyland and Wallace, 2001) and copula-based scenarios that preserve dependence between risk factors (Kaut and Wallace, 2011). Robust optimisation offers an alternative when distributions are hard to estimate (Ben-Tal and Nemirovski, 1998; Bertsimas and Sim, 2004; Bertsimas *et al*., 2011).

These tools have been applied extensively to the oil supply chain. Reviews cover strategic and tactical models for the crude oil supply chain (Sahebi *et al*., 2014) and the downstream oil supply chain (Lima *et al*., 2016). Operational planning frameworks link crude selection with refinery operations (Neiro and Pinto, 2004), network design models address downstream infrastructure (Fernandes *et al*., 2013), and refinery planning models incorporate financial and operational risk through scenarios (Pongsakdi *et al*., 2006; Khor *et al*., 2008). Ship routing and scheduling models support the transport leg (Christiansen *et al*., 2013). Most of this work, however, treats the crude slate as an input to refinery economics and models supply risk only through price uncertainty; the explicit allocation of volume across geopolitically exposed suppliers remains comparatively underdeveloped.

A substantial applied literature describes how energy companies organise procurement. Frameworks for strategic procurement optimisation in oil and gas (Okonkwo *et al*., 2018a), inventory availability and plant uptime (Okonkwo *et al*., 2018b), materials readiness (Okonkwo *et al*., 2021a), asset lifecycle and inventory visibility (Okonkwo *et al*., 2023b), predictive procurement planning (Okonkwo *et al*., 2024c) and national-scale supply chain optimisation through integrated IT and procurement systems (Okonkwo *et al*., 2025) show how procurement decisions shape operational continuity. Digital governance and secure, scalable supply chain systems for national energy reliability (Okonkwo *et al*., 2024a; Okonkwo *et al*., 2024b), reviews of procurement strategy, ERP adoption and digital supply chain models (Okonkwo *et al*., 2024d; Okonkwo *et al*., 2024e), automation on service management platforms (Okonkwo *et al*., 2024f), integration of IT systems engineering with supply chain operations (Okonkwo *et al*., 2023a) and regulatory-compliant procurement in high-risk energy environments (Okonkwo *et al*., 2021b) complete the picture.

Environmental, social and governance requirements increasingly shape supplier choice, through digital twin compliance models for procurement in oil, gas and utilities (Ike *et al*., 2025), automated ESG reporting in energy projects (Abioye *et al*., 2023), and ESG-integrated and green procurement frameworks (Okojie *et al*., 2020; Akinleye, 2023; Akin-Oluyomi *et al*., 2023a; Efobi *et al*., 2022a). Digitalisation supports these processes through automation and digital twins (Akinlade *et al*., 2024; Akinleye and Adeyoyin, 2021), integrated transparency platforms (Okoruwa *et al*., 2024; Okoruwa *et al*., 2025), end-to-end visibility (Nnabueze *et al*., 2021), blockchain and smart contracts for logistics and supplier payments (Ekwunife *et al*., 2024; Akomolafe *et al*., 2022), and guardrails for

autonomous value chains (Ogundairo, 2025). Lean and data-driven optimisation (Ike *et al*., 2022; Efobi *et al*., 2022b), supply chain governance, leadership and analytics (Akin-Oluyomi and Akhigbe, 2022; Akin-Oluyomi and Akhigbe, 2023a; Akin-Oluyomi and Akhigbe, 2023b), workforce and enterprise risk frameworks (Falemi *et al*., 2023; Falemi *et al*., 2024), demand forecasting and forecasting-based resource allocation (Aifuwa *et al*., 2020; Unamma *et al*., 2018), reverse logistics (Anene *et al*., 2025), real-time risk dashboards (Filani *et al*., 2022), KPI systems (Sakyi *et al*., 2022; Tonoyan *et al*., 2024b), route optimisation (Tonoyan *et al*., 2025) and the coupling of energy efficiency with transport logistics (Opara *et al*., 2024) provide the data and organisational foundation that a monthly allocation model requires.

Because the price of resilience is ultimately a financial decision, the model also draws on work in decision analytics and financial planning. Scenario-based financial modelling for strategic decisions (Filani *et al*., 2023), data-driven executive decision systems (Lawal and Oduleye, 2019), analytics-based capital allocation (Lawal and Oduleye, 2021a) and the alignment of financial planning analytics with strategy (Lawal and Oduleye, 2021b) frame resilience spending as an investment choice. Predictive forecasting and planning models (Medon and Oduleye, 2024; Medon and Oduleye, 2023; Oduleye and Medon, 2021; Oduleye and Medon, 2023), predictive budgeting from operational and market signals (Adesuyi *et al*., 2022), cost governance and variance analytics (Adesuyi *et al*., 2023; Aliliele *et al*., 2024), capital efficiency optimisation (Walawalkar *et al*., 2025), machine-learning demand and cash-flow forecasting (Tonoyan *et al*., 2021a; Tonoyan *et al*., 2021b), geospatial predictive analytics for market-entry decisions (Tonoyan *et al*., 2022a) and simulation-based process and cost optimisation (Tonoyan *et al*., 2022b; Tonoyan *et al*., 2022c) supply the forecasting layer, while treasury models for FX risk and cross-border finance (Dada *et al*., 2021; Isiekwu *et al*., 2021) and revenue optimisation in energy distribution (Nnabueze *et al*., 2024) address the financial exposure that accompanies multi-currency, multi-origin buying.

On the governance side, predictive financial risk assessment (Agu *et al*., 2025), data-driven risk evaluation and financial resilience (Akomolafe and Agu, 2019a; Akomolafe and Agu, 2019b), compliance risk models (Akomolafe *et al*., 2023; Akomolafe *et al*., 2025), predictive risk detection and performance intelligence in public systems (Adelanwa *et al*., 2023b; Adelanwa *et al*., 2023a; Adelanwa *et al*., 2024), data-mining techniques for fraud detection (Unamma *et al*., 2021), legal, financial and data governance for enterprise analytics (Ashore-Onisemo *et al*., 2024), and multi-layered risk allocation for public-private partnerships (Ike *et al*., 2024) show how organisations formalise risk appetite. Risk-based decision models that balance speed against safety (Eze *et al*., 2024), regulatory scenario analysis (Akinola *et al*., 2020) and models that balance cost against operational continuity (Anyanwu, 2020) are close analogues of the cost and resilience trade-off examined in this paper.

2.5 Energy infrastructure, transition and the 2025 risk landscape

Many disruptions at the point of origin are caused not by politics but by infrastructure. Risk-based inspection, reliability-centred maintenance and integrity management of upstream equipment (Obetta, 2018; Obetta, 2019; Obetta, 2020; Obetta *et al*., 2021), liability mitigation in high-value energy service contracts (Uchechi and Ominyi, 2019), process safety in offshore pipeline commissioning (Oduro, 2023), decision-making in process upsets and loss detection and flare attribution in liquefaction systems (Ekelemu *et al*., 2025; Ekelemu and Akano, 2025), and lifecycle risk assessment of produced water (Falegan and Aniebonam, 2022) all bear on the reliability of supply. Upstream investment and asset decisions, including capital budgeting for field development (Nwangwu *et al*., 2021), reservoir forecasting (Nwangwu *et al*., 2020), value extraction from mature assets (Nwangwu *et al*., 2022), due diligence in energy acquisitions (Nwangwu *et al*., 2023), governance of multinational infrastructure projects (Amayo *et al*., 2023) and predictive schedule-risk methods (Zhou *et al*., 2024), shape how much spare capacity suppliers can offer when others fail.

Cyber-physical threats add a further channel. Studies of operational technology security in energy utilities (Adegbite *et al*., 2020; Adegbite *et al*., 2022), threat detection in industrial control and SCADA networks (Adegbite *et al*., 2023; Amadi *et al*., 2025), vulnerability governance and cyber risk quantification (Adegbite *et al*., 2024; Adegbite *et al*., 2025), zero-trust architectures for critical infrastructure (Ahmed *et al*., 2021), identity and access governance in hybrid cloud environments (Unamma *et al*., 2024), cyber risk quantification for prioritising security investment (Dosunmu and Ogundele, 2024) and secure data exchange for SCADA-controlled systems (Shittu *et al*., 2022) show that pipelines, terminals and grids can be disrupted without a single shot being fired. Grid automation, microgrid integration, digital twins and smart grid architectures (Shittu *et al*., 2025a; Shittu *et al*., 2025b; Shittu and Shittu, 2024; Adenuga, 2022), together with predictive analytics for ageing electrical infrastructure (Idima *et al*., 2023), matter for the electrically driven pumping and terminal systems on which crude exports depend.

The supplier set itself is shaped by longer-run forces. The energy transition alters demand for crude and the economics of producers through diversification pathways for fossil-fuel regions (Komi, 2025), the measurement of a just transition for displaced workers (Komi and Adamolekun, 2024), resilient microgrid control and energy sovereignty (Komi and Ganiu, 2023), hydrogen as an energy carrier (Shittu *et al*., 2019; Monye *et al*., 2025), portfolio optimisation of renewable assets (Ilesanmi *et al*., 2024), carbon utilisation in mature oil fields (Ijiga *et al*., 2023) and renewable project management in emerging markets (Amayo *et al*., 2024). Foreign policy and regional diplomacy influence which suppliers are politically accessible, as shown by work on climate diplomacy (Liadi, 2022), regional engagement (Liadi, 2023a), economic interdependence with major partners (Liadi, 2023b) and cross-border security cooperation (Liadi, 2024). Trade and sanctions compliance determines which cargoes can legally be bought, through export controls and sanctions (Jones and Ominyi, 2023), legal barriers to import and export (Jones and Ominyi, 2020), market access under trade agreements (Jones and Ominyi, 2022) and risk-based import compliance (Aneke and Adesemoye, 2021).

The year 2025 offered several episodes that are directly relevant to crude procurement. Table 1 summarises the events used to calibrate the stress regimes in Section 5. The common lesson is that disruptions were route-specific and

partly correlated: the Hormuz and Red Sea episodes both originated in the wider Middle East confrontation (S&P Global, 2025; Bloomberg, 2025; Notteboom *et al*., 2024), while the Black Sea strikes reflected the separate Russia and Ukraine conflict (Marine Insight, 2025). A model that treats each supplier's disruption risk as independent would understate the probability of losing two Middle East sources in the same month. The CPC episode also illustrates that export terminals and their mooring systems are single points of failure for whole crude streams (Obetta and Ninduwezuor-Ehiobu, 2018).

Table 1: Geopolitical events of 2025 used to calibrate stress regimes

Period	Event	Procurement effect	Regime in model
June 2025	Israel and Iran military confrontation; threats to Hormuz	Freight and war-risk premiums jump; Gulf loadings slowed	Hormuz escalation
July 2025	Houthi attacks sink Magic Seas and Eternity C	Red Sea war-risk premiums rise; more Cape diversions	Red Sea resurgence
Nov. 2025	Naval drones damage CPC mooring near Novorossiysk	CPC Blend loadings interrupted; Black Sea insurance rises	Black Sea strikes
2025 overall	Brent averages about USD 69/bbl amid surplus supply	Low flat price; discounts widen on risky grades	Baseline 2025
Hypothetical	Simultaneous Middle East and Black Sea stress	Correlated outages with price spike	Compound stress

Sources: EIA (2025a, 2025b); S&P Global (2025); Bloomberg (2025); Marine Insight (2025). The compound regime is constructed for stress testing and does not describe an observed event.

Three gaps emerge from this review. First, energy security research measures diversification and import risk well at national level (Cohen *et al*., 2011; Le Coq and Paltseva, 2009; Ge and Fan, 2013; Desogus *et al*., 2023) but rarely converts these measures into firm-level monthly volume decisions with contractual, quality and lead-time constraints. Second, supplier selection and diversification models (Sawik, 2011; Torabi *et al*., 2015; Wang *et al*., 2020) handle disruption risk, but they seldom combine a transparent, committee-facing ranking of qualitative criteria with correlated, geopolitically driven tail risk and route-specific transport exposure. Third, the applied procurement and resilience literature from emerging economies (Okonkwo *et al*., 2018a; Nwangwu *et al*., 2025; Efobi *et al*., 2023) provides rich frameworks and governance practice but few quantitative allocation rules. The conceptual model in Section 3 and the methodology in Section 4 address all three by linking an AHP-weighted TOPSIS screen to a scenario-based mean and CVaR allocation with security, chokepoint and lead-time constraints, calibrated to the events of 2025.

3. Conceptual Model

The literature synthesis points to a simple causal structure, summarised in Fig 1. Geopolitical drivers, such as conflict near chokepoints, sanctions, terminal incidents and price or freight shocks, act on two levels. They shape the probability and correlation of supply disruptions (Caldara and Iacoviello, 2022; Kilian, 2008; Desogus *et al*., 2023), and they shift the priorities of the procurement committee, for example by raising the weight placed on supply security after a year such as 2025 (Cherp and Jewell, 2014; Okonkwo *et al*., 2021b). Each candidate supplier is described by four attributes: purchase cost, transport risk, lead time and supply security. These attributes are measured by the indicators defined in Section 4 and enter the decision process twice, first as criteria for ranking and then as costs, probabilities and constraints for allocation (Chai *et al*., 2013; Sawik, 2011).

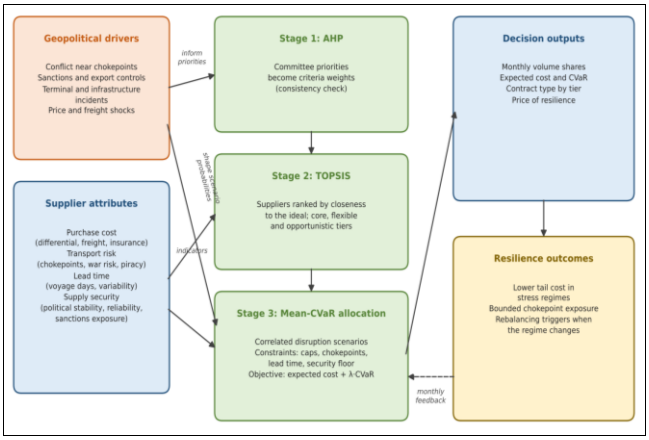

Fig 1: Conceptual model linking geopolitical drivers and supplier attributes to procurement decisions and resilience outcomes

The decision process has three linked stages. Stage 1 converts committee judgement into criteria weights. Stage 2 uses those weights to rank suppliers and assign them to tiers that govern contract type. Stage 3 allocates monthly volume by trading expected cost against tail cost over correlated disruption scenarios, within limits on supplier shares, chokepoint exposure, average lead time and portfolio supply security (Rockafellar and Uryasev, 2000; Torabi *et al*., 2015). The outputs are volume shares, the expected and tail cost of the portfolio, the contract mix and an explicit price of resilience. These outputs produce resilience outcomes: lower tail cost in stress regimes, bounded exposure to any single chokepoint and a set of rebalancing triggers (Christopher and Peck, 2004; Tomlin, 2006). Observed outcomes feed back into the next monthly cycle, which makes the model a recurring decision routine rather than a one-off study (Okonkwo *et al*., 2024c; Filani *et al*., 2023).

Four propositions follow from this structure and are examined in the numerical case. First, because disruptions on routes exposed to the same geopolitical factor are correlated, concentration on such routes raises tail cost more than it raises expected cost; diversification across independent corridors should therefore lower CVaR at little expected-cost penalty. Second, a static ranking of suppliers and an optimal allocation will diverge whenever a low-ranked supplier offers a discount large enough to justify a capped share, so rankings are better suited to setting contract tiers than to setting volumes. Third, explicit structural constraints, such as a supply-security floor and chokepoint caps, deliver most of the resilience benefit, leaving the risk-aversion parameter with a secondary role. Fourth, re-optimising when the regime changes should reduce tail cost relative to holding a fixed portfolio, which supports pre-agreed rebalancing triggers. Section 5 reports evidence on each proposition and Section 6 interprets it.

4. Methodology

4.1 Problem setting

Consider a refiner, or a national oil company buying on behalf of domestic refineries, that must procure a fixed monthly crude volume Q from a set I of candidate suppliers. Each supplier i offers a grade at a price differential to Brent, ships along a known route with its own freight, insurance and chokepoint exposure, delivers after a stochastic lead time, and is subject to a probability that the cargo is lost or delayed in a given month because of conflict, sanctions, force majeure, theft or terminal damage. Volumes from each supplier are limited by term contract availability and by the refinery's crude slate.

The decision maker wants a monthly allocation $x = (x_1..., x_n)$, where x_i is the share of Q bought from supplier i, that keeps expected delivered cost low while limiting the cost of the worst plausible months. Four criteria are named explicitly:

- **Purchase cost:** The landed cost per barrel, built from the Brent price, the grade differential, freight and insurance.
- **Transport risk:** Exposure of the route to chokepoints, war-risk zones and piracy, which affects both the probability of disruption and the volatility of freight and insurance.
- **Lead time:** Expected days from loading to discharge and its variability, which tie up working capital and create a risk of run cuts if cargoes arrive late.
- **Supply security:** The political stability of the exporting country, the reliability of the seller in honouring contracts, and the exposure of the trade to sanctions.

Because the criteria are partly qualitative and partly monetary, and because disruptions are rare, correlated and costly, the problem is addressed with a hybrid model rather than a single optimisation.

The model proceeds in three stages, summarised here and formalised below. Stage 1 sets criteria weights with AHP. Stage 2 scores suppliers with TOPSIS and assigns them to tiers. Stage 3 allocates volume with a scenario-based mean and CVaR linear programme that embeds the same four criteria as costs, probabilities and constraints. A fourth, operational step applies rebalancing triggers when indicators show a change of regime.

4.2 Notation

Table 2: Notation

Symbol	Meaning
I, i	Set of candidate suppliers and its index, n = |I|
Q	Monthly volume to procure (barrels)
x_i	Share of Q allocated to supplier i (decision variable)
P	Brent benchmark price (USD/bbl)
d_i, f_i, h_i	Grade differential, freight and insurance (incl. war risk) for supplier i (USD/bbl)
L_i, σ_i	Expected lead time and its standard deviation (days)
r	Annual cost of capital applied to oil in transit
p_i	Monthly probability that supplier i's cargo is disrupted
TR_i, SS_i	Transport risk index and supply security index (0 to 10)
u_i	Maximum share available from supplier i
G, Γ_g	Chokepoint groups and the cap on exposure to group g
S, s, c_i^s	Scenario set, scenario index and delivered cost of supplier i in scenario s
α, λ	CVaR confidence level and weight on tail risk (0 to 1)
S_{min}, L_{max}	Minimum portfolio supply-security score; maximum average lead time

4.3 Stage 1: criteria weights by AHP

Decision makers compare the four criteria pairwise on Saaty's 1 to 9 scale, giving a reciprocal matrix A. The weight vector w is the normalised principal eigenvector of A:

$$A\,w = \lambda_{max}\,w,\ \Sigma_k\, w_k = 1 \tag{1}$$

Consistency is checked with the consistency index $CI = (\lambda_{max} - m)/(m - 1)$ and the consistency ratio $CR = CI/RI$, where $m = 4$ criteria and the random index $RI = 0.90$. Judgements are accepted when $CR < 0.10$ (Saaty, 1980; Saaty, 1990).

4.4 Indicators for the four criteria

Effective purchase cost: The landed cost of supplier i is the benchmark plus differential, freight and insurance. Lead time is converted into money through the carrying cost of oil in transit, so the effective cost used for ranking is:

$$C_i = (P + d_i) + f_i + h_i + (P + d_i) \cdot r \cdot L_i / 365 \tag{2}$$

Transport risk is scored from 0 (negligible) to 10 (severe) on chokepoint transits, active war-risk listings and piracy history along the route. **Lead time** enters TOPSIS directly in days. **Supply security** is the mean of three 0 to 10 sub-scores: political stability, contract reliability and sanctions exposure (higher is better). Security sub-scores follow the logic of supplier risk assessment and compliance-risk frameworks, including control-effectiveness approaches to technology risk and regulatory reporting (Akin-Oluyomi *et al*., 2023b; Akomolafe *et al*., 2023; Okonkwo *et al*., 2021b; Okwesa *et al*., 2023), and the carrying-cost term reflects standard working-capital practice (Oduleye and Medon, 2023; Tonoyan *et al*., 2021b). These indicators are deliberately simple so that a procurement committee can audit and update them monthly, in line with data governance and auditability practice for high-volume financial operations (Sakyi *et al*., 2022; Babatope *et al*., 2023; Okwesa and Ashore-Onisemo, 2023).

4.5 Stage 2: supplier ranking by TOPSIS

Let x_{ik} be the value of supplier i on criterion k. TOPSIS vector-normalises the matrix, applies the AHP weights, and measures distances to the ideal and anti-ideal points:

$$v_{ik} = w_k \cdot x_{ik} / \sqrt{(\Sigma_i\, x_{ik}^2)} \tag{3}$$

$$D_i^+ = \sqrt{(\Sigma_k\, (v_{ik} - v_k^+)^2)},\ D_i^- = \sqrt{(\Sigma_k\, (v_{ik} - v_k^-)^2)} \tag{4}$$

$$CC_i = D_i^- / (D_i^+ + D_i^-) \tag{5}$$

For cost, transport risk and lead time the ideal is the column minimum; for supply security it is the column maximum. The closeness coefficient CC_i lies between 0 and 1 (Behzadian *et al*., 2012). Suppliers are assigned to a **strategic core** tier (CC ≥ 0.60), a **flexible** tier (0.35 ≤ CC < 0.60) and an **opportunistic** tier (CC < 0.35). Tiers inform contract type (term, frame or spot) and are used in Section 6 to check that the optimised portfolio keeps a strong core.

4.6 Scenario generation with correlated disruptions

Stage 3 needs a distribution of delivered costs. For each scenario s and supplier i, a disruption indicator D_i^s is drawn from a Gaussian copula, following copula-based scenario

generation (Kaut and Wallace, 2011). A common geopolitical factor Z^s and idiosyncratic shocks ε_i^s are combined with loadings ρ_i:

$$Y_i^s = \rho_i Z^s + \sqrt{(1 - \rho_i^2)}\, \varepsilon_i^s,\ D_i^s = 1 \text{ if } Y_i^s > \Phi^{-1}(1 - p_i),\ \text{else } 0 \quad (6)$$

Loadings are highest for Gulf and Red Sea routes (0.5 to 0.6), moderate for the Black Sea (0.35) and near zero for Atlantic origins, so that Middle East outages cluster. The common factor also drives a spot price spike $\Pi^s = \kappa \cdot \max(Z^s, 0) + noise$, because replacement cargoes are bought in the same market that the shock has tightened. The delivered cost of supplier i in scenario s is:

$$c_i^s = (P + d_i + f_i + h_i) + \Delta F_i^s + (P + d_i)\, r\, L_i^s/365 + \delta \max(L_i^s - L_i - \sigma_i, 0) + D_i^s \cdot \theta \cdot (\rho_{rep} + \Pi^s) \quad (7)$$

Here ΔF_i^s is freight and insurance volatility (larger when a regime raises war-risk premiums), L_i^s is a normally distributed lead time truncated at one day, δ is a late-arrival penalty per barrel per day beyond one standard deviation, reflecting demurrage and run-cut costs (Okonkwo *et al*., 2020), θ is the share of a monthly cargo lost when disruption occurs, and ρ_{rep} is the premium paid for a prompt replacement cargo. Regimes are represented by multiplying baseline disruption probabilities and insurance costs for the exposed routes and by raising κ, in the spirit of scenario-based and regulatory scenario analysis (Filani *et al*., 2023; Akinola *et al*., 2020).

4.7 Stage 3: mean and CVaR allocation model

With |S| equally likely scenarios, the CVaR of portfolio cost at level α is linearised with an auxiliary threshold η and excess variables z^s (Rockafellar and Uryasev, 2000; Rockafellar and Uryasev, 2002; Krokhmal *et al*., 2002). The allocation model is:

$$\min\ (1 - \lambda) \cdot (1/|S|)\, \Sigma_s \Sigma_i c_i^s x_i + \lambda \cdot [\eta + 1/((1 - \alpha)|S|)\, \Sigma_s z^s] \quad (8)$$

subject to

$$z^s \geq \Sigma_i c_i^s x_i - \eta,\ z^s \geq 0 \text{ for all } s \quad (9)$$

$$\Sigma_i x_i = 1,\ 0 \leq x_i \leq u_i \quad (10)$$

$$\Sigma_{i \in g} x_i \leq \Gamma_g \text{ for each chokepoint group } g \quad (11)$$

$$\Sigma_i SS_i x_i \geq S_{min} \quad (12)$$

$$\Sigma_i L_i x_i \leq L_{max} \quad (13)$$

Equation (8) is the objective: a blend of expected cost and tail cost controlled by λ. Constraint (9) defines the tail excess, (10) enforces full coverage and contractual caps, (11) limits exposure to any single chokepoint, (12) imposes a minimum portfolio supply-security score, and (13) caps the volume-weighted lead time. Caps u_i also act as a concentration control: with every $u_i \leq 0.30$, at least four suppliers are always used and the HHI cannot exceed 0.30. The model is a linear programme with $n + 1 + |S|$ variables and is solved in under a second for several thousand scenarios with an open-source solver (HiGHS).

4.8 Decision procedure

The model is intended to be run monthly within the procurement cycle, in the spirit of predictive procurement planning for operational uptime (Okonkwo *et al*., 2024c) and scenario-based strategic planning (Filani *et al*., 2023):

1. Update market inputs (Brent, differentials, freight and war-risk quotes) and qualitative scores from ERP and vendor-performance systems (Okonkwo *et al*., 2024d; Abdulrazaq *et al*., 2025); re-run AHP only when the committee's priorities change.
2. Re-score suppliers with TOPSIS and review tier membership; any supplier dropping a tier triggers a contract review.
3. Identify the prevailing regime from leading indicators (war-risk listings, chokepoint transit counts, sanctions announcements, terminal incident reports), ideally surfaced on real-time risk dashboards and predictive early-warning systems (Filani *et al*., 2022; Tonoyan *et al*., 2024b; Okwesa *et al*., 2024).
4. Generate scenarios for that regime, solve the allocation model, and compare it with the current book of term and spot commitments.
5. Rebalance within contractual flexibility, prioritising reductions on suppliers whose risk has risen and additions on core-tier suppliers with spare capacity, using established supplier relationship and contract governance channels (Ike *et al*., 2021; Akin-Oluyomi *et al*., 2024; Okonkwo *et al*., 2019).

5. Results

5.1 Case description and data

The model is applied to a stylised coastal refinery in the western Mediterranean that processes about 200,000 barrels per day and therefore buys roughly 6.0 million barrels per month. Eight origins are considered, chosen to span the main supply corridors open to a Mediterranean buyer in 2025: Saudi Arabia (Arab Light loaded at Yanbu), Iraq (Basrah Medium, routed around the Cape because of Red Sea risk), Nigeria (Bonny Light), the United States (WTI Midland), Norway (Johan Sverdrup), Kazakhstan (CPC Blend), Libya (Es Sider) and Brazil (Búzios).

Inputs are calibrated to 2025 conditions but are illustrative rather than quoted market data. Brent is set at USD 69 per barrel, close to the EIA's reported 2025 average. Differentials reflect typical quality and risk discounts, freight and insurance reflect route length and war-risk exposure, and baseline monthly disruption probabilities reflect each origin's recent record of force majeure, terminal outages and security incidents, including failures of export moorings, offloading hoses and floating storage systems (Obetta and Ninduwezuor-Ehiobu, 2018; Obetta *et al*., 2025; Obetta *et al*., 2022). The cost of capital is 8% per year, the replacement premium is USD 7 per barrel, 80% of a disrupted cargo is assumed lost for the month, and the late-arrival penalty is USD 0.06 per barrel per day. Tables 3 and 4 list the supplier data.

Table 3: Cost and lead-time inputs by supplier (USD/bbl unless stated)

Supplier	Diff. to Brent	Freight	Insur. & war risk	Transit carry	Effective cost C_i	Lead time (days)	Lead SD (days)	Max share
Saudi Arabia (Arab Light, Yanbu)	+0.80	1.90	0.30	0.21	72.21	14	3.0	30.0%
Iraq (Basrah Medium)	-1.80	3.40	0.55	0.56	71.71	38	7.0	30.0%
Nigeria (Bonny Light)	+1.20	1.70	0.20	0.18	72.28	12	3.5	25.0%
United States (WTI Midland)	+0.60	2.30	0.05	0.26	72.21	17	2.0	30.0%
Norway (Johan Sverdrup)	+1.30	1.60	0.03	0.17	72.10	11	1.5	15.0%
Kazakhstan (CPC Blend)	-2.40	1.20	0.70	0.13	68.63	9	3.0	20.0%
Libya (Es Sider)	-0.30	0.90	0.45	0.08	70.13	5	2.5	20.0%
Brazil (Buzios)	-0.20	2.90	0.06	0.33	72.09	22	3.0	20.0%

Effective cost follows Equation (2) with P = 69 and r = 8%. Values are stylised to 2025 conditions for illustration.

Table 4: Route, transport risk and supply-security inputs

Supplier	Route and exposure	TR_i	Political	Reliab.	Sanct.	SS_i	p_i per month
Saudi Arabia (Arab Light, Yanbu)	Yanbu, Red Sea (north), Suez	5.5	6.5	8.5	8.0	7.67	4.0%
Iraq (Basrah Medium)	Basrah, Hormuz, Cape of Good Hope	8.5	4.0	6.5	7.0	5.83	8.0%
Nigeria (Bonny Light)	Bonny, Gulf of Guinea, Gibraltar	5.0	3.5	5.0	8.0	5.50	6.0%
United States (WTI Midland)	US Gulf Coast, Atlantic, Gibraltar	1.5	9.0	8.5	9.5	9.00	1.0%
Norway (Johan Sverdrup)	North Sea, Atlantic, Gibraltar	1.0	9.5	9.5	10.0	9.67	1.0%
Kazakhstan (CPC Blend)	Novorossiysk (CPC), Turkish Straits	7.5	5.0	6.0	5.0	5.33	10.0%
Libya (Es Sider)	Es Sider, central Mediterranean	5.0	2.5	4.0	6.5	4.33	12.0%
Brazil (Buzios)	Santos Basin, South Atlantic, Gibraltar	2.0	7.5	8.0	9.0	8.17	2.0%

Transport risk: 0 = negligible, 10 = severe. Security sub-scores: 0 = very weak, 10 = very strong. p_i is the baseline probability that a monthly cargo is disrupted.

5.2 Criteria weights

A procurement committee for an import-dependent refiner was assumed to rank supply security first, purchase cost second, transport risk third and lead time fourth, reflecting the 2025 experience that physical availability, not price, was the binding concern in stress months. The pairwise comparison matrix and resulting weights are shown in Table 5. The consistency ratio is 0.011, well below the 0.10 threshold.

Table 5: AHP pairwise comparison matrix and criteria weights

Criterion	Purchase cost	Transport risk	Lead time	Supply security	Weight
Purchase cost	1	2	3	1/2	0.277
Transport risk	1/2	1	2	1/3	0.160
Lead time	1/3	1/2	1	1/4	0.095
Supply security	2	3	4	1	0.467

λ_{max} = 4.031, CI = 0.010, RI = 0.90, CR = 0.011.

5.3 Supplier ranking

Table 6 reports the TOPSIS results. Norway and the United States lead because they combine near-average cost with the lowest transport risk and the highest security scores; Brazil follows despite its long voyage. Saudi Arabia sits in the flexible tier, penalised by Red Sea exposure. Libya, Kazakhstan and Iraq rank lowest: they are among the cheapest barrels on an effective-cost basis, but their transport risk and security scores pull them toward the anti-ideal. Iraq is also penalised by a 38-day voyage around Africa.

Table 6: TOPSIS distances, closeness coefficients and tiers

Rank	Supplier	D^+	D^-	CC_i	Tier
1	Norway (Johan Sverdrup)	0.012	0.155	0.929	Strategic core
2	United States (WTI Midland)	0.028	0.137	0.833	Strategic core
3	Brazil (Buzios)	0.048	0.117	0.710	Strategic core
4	Saudi Arabia (Arab Light, Yanbu)	0.069	0.094	0.576	Flexible
5	Nigeria (Bonny Light)	0.106	0.066	0.384	Flexible
6	Libya (Es Sider)	0.130	0.071	0.352	Flexible
7	Kazakhstan (CPC Blend)	0.123	0.059	0.323	Opportunistic
8	Iraq (Basrah Medium)	0.134	0.035	0.205	Opportunistic

The ranking is informative but incomplete. It says that Norway is a better supplier than Kazakhstan on the committee's weights; it does not say whether a refiner should buy any CPC Blend at all, or how much, when CPC is USD 3.58 per barrel cheaper than WTI on an effective basis. That is the role of Stage 3.

5.4 Optimal allocation in the baseline 2025 regime

Six strategies are compared using 3,000 baseline scenarios: buying everything from the cheapest source (S1); minimising expected cost subject only to supplier caps (S2); splitting volume equally (S3); allocating in proportion to TOPSIS scores (S4); the mean and CVaR model with λ =

0.5 and $\alpha = 0.95$ (S5); and the same model with a supply-security floor $S_{min} = 7.5$ (S6), which is the recommended configuration. The Hormuz chokepoint group, the Red Sea group and the Black Sea group are each capped at 35%. Table 7 shows the allocations and Table 8 the performance metrics.

Table 7: Allocation by strategy, baseline 2025 regime (% of monthly volume)

Strategy	SAU	IRQ	NGA	USA	NOR	KAZ	LBY	BRA
S1 Single cheapest source	0	0	0	0	0	100.0	0	0
S2 Cost-minimising (caps only)	0	25.0	0	0	15.0	20.0	20.0	20.0
S3 Equal split	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
S4 TOPSIS-proportional	14.3	5.1	9.5	20.7	16.1	8.0	8.7	17.6
S5 Mean-CVaR, λ = 0.5	0	1.7	0.5	22.9	15.0	20.0	20.0	20.0
S6 Resilient: mean-CVaR + security floor	0	0	0	30.0	15.0	20.0	15.0	20.0

SAU Saudi Arabia, IRQ Iraq, NGA Nigeria, USA United States, NOR Norway, KAZ Kazakhstan, LBY Libya, BRA Brazil. Shaded row: recommended portfolio.

Table 8: Performance of each strategy, baseline 2025 regime

Strategy	Expected cost (USD/bbl)	Std. dev.	VaR 95%	CVaR 95%	HHI	Avg. lead (days)	Security SS	TR
S1 Single cheapest source	69.29	1.89	74.47	75.29	1.000	9.0	5.33	7.50
S2 Cost-minimising (caps only)	71.36	0.77	72.93	73.62	0.205	18.4	6.48	5.18
S3 Equal split	71.77	0.53	72.89	73.27	0.125	16.0	6.94	4.50
S4 TOPSIS-proportional	71.95	0.43	72.84	73.19	0.146	15.4	7.57	3.56
S5 Mean-CVaR, λ = 0.5	71.37	0.62	72.48	73.03	0.195	13.4	7.20	3.56
S6 Resilient: mean-CVaR + security floor	71.44	0.57	72.54	73.07	0.215	13.7	7.50	3.25

Four results stand out. First, single sourcing is cheapest on average (USD 69.29) because CPC Blend carries a deep discount, but its CVaR of USD 75.29 is the worst of all strategies even in a calm year, and it concentrates the entire supply on one route. Second, the cost minimiser (S2) diversifies only because caps force it to: it fills Kazakhstan, Libya, Norway and Brazil to their limits and takes 25% from Iraq, and its average security score of 6.48 and Hormuz exposure of 25.0% would be uncomfortable for most committees. Third, the equal split and TOPSIS-proportional rules (S3, S4) achieve good tail outcomes but pay for them with expected costs USD 0.34 and USD 0.51 per barrel above S6, because they keep buying suppliers that add cost without adding protection.

Fourth, the recommended portfolio S6 (USA 30.0%, KAZ 20.0%, BRA 20.0%, NOR 15.0%, LBY 15.0%) costs USD 0.07 per barrel more than S2 in expectation, about USD 0.45 million per month at 6.0 million barrels, while reducing baseline CVaR by USD 0.55 per barrel, removing Hormuz exposure entirely, raising the security score to 7.50 and cutting the average voyage to 13.7 days. Compared with S5, the security floor moves about seven percentage points from Libya, Iraq and Nigeria to the United States at a cost of only USD 0.07 per barrel. Notably, S6 still fills Kazakhstan to its cap and takes 15% from Libya: the model accepts discounted, riskier barrels as long as they are held in proportions that the rest of the portfolio can absorb.

5.5 The cost and tail-risk frontier

Varying λ from 0 to 1 with the security floor in place traces the frontier in Fig 2. The frontier is short and steep near the origin: moving from $\lambda = 0$ to $\lambda = 1$ lowers CVaR by only USD 0.04 per barrel while raising expected cost by USD 0.17. In the baseline regime, therefore, most of the resilience comes from the structural constraints (caps, chokepoint limits and the security floor) rather than from the risk-aversion parameter. The equal split and TOPSIS-proportional rules lie well inside the frontier, which confirms that heuristic diversification is dominated by optimised diversification.

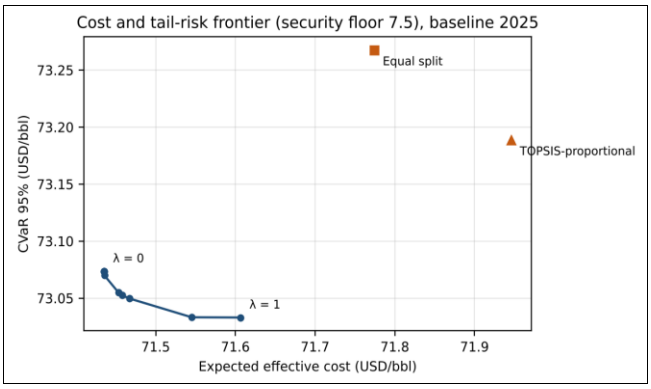

Fig 2: Expected cost versus 95% CVaR for optimised portfolios (λ from 0 to 1) and two heuristic rules, baseline 2025 regime

5.6 Stress testing under 2025 geopolitical regimes

Each regime multiplies baseline disruption probabilities and war-risk costs for the exposed routes and raises the scale of the price spike. The Hormuz regime multiplies Iraq's disruption probability by four and adds a USD 8 per barrel spike factor; the Red Sea regime triples Saudi exposure; the Black Sea regime triples the CPC risk; and the compound regime combines elevated Middle East, Black Sea, Libyan and West African risk with a USD 10 spike factor. Table 9 compares tail costs, and Fig 3 visualises them.

Table 9: Expected cost and CVaR 95% (USD/bbl) by strategy and regime

Regime	S1 Single cheapest	S2 Cost-min.	S3 Equal split	S5 Mean-CVaR	S6 Resilient (fixed)	S6 re-optimised
Baseline 2025	69.28 / 75.30	71.38 / 73.57	71.78 / 73.27	71.38 / 73.02	71.45 / 73.03	71.45 / 73.02
Hormuz escalation	69.69 / 83.05	72.61 / 78.96	72.53 / 77.08	71.63 / 75.33	71.61 / 74.87	71.84 / 74.50
Red Sea resurgence	69.35 / 76.63	71.46 / 74.23	71.97 / 74.09	71.40 / 73.37	71.46 / 73.33	71.46 / 73.33
Black Sea strikes	71.71 / 78.26	71.89 / 74.68	72.11 / 74.01	71.88 / 74.06	71.94 / 73.91	72.06 / 73.56
Compound stress	72.15 / 89.46	73.07 / 81.60	73.01 / 79.27	72.31 / 77.86	72.25 / 77.13	72.49 / 75.89

Each cell shows expected cost / CVaR 95%. 'Fixed' keeps the baseline S6 allocation; 're-optimised' solves the S6 model again with the regime's scenarios.

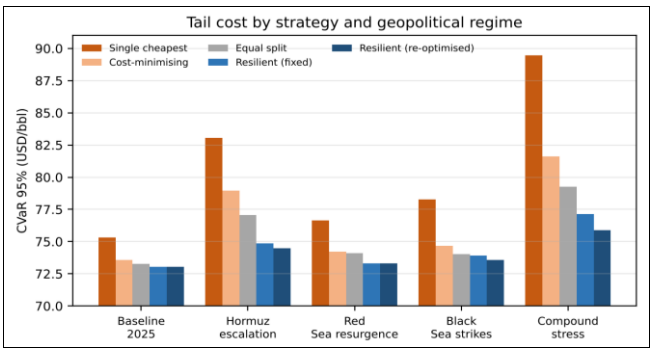

Fig 3: 95% CVaR of delivered cost by strategy across the five geopolitical regimes

The fixed resilient portfolio holds up well. Under Hormuz escalation its CVaR rises to USD 74.87, compared with USD 78.96 for the cost minimiser and USD 83.05 for single sourcing, because it carries no Hormuz exposure and only modest Middle East correlation. Under compound stress its CVaR is USD 77.13 versus USD 81.60 for S2, a protection of USD 4.47 per barrel, or about USD 26.8 million in a bad month. Single sourcing reaches USD 89.46, roughly USD 74.0 million more than S6 in the same tail month.

Re-optimising once a regime is recognised adds a further layer of protection. Fig 4 shows how the recommended allocation shifts. Under Black Sea strikes the model cuts Kazakhstan from 20.0% to 7.9% and spreads the volume over Saudi Arabia, Iraq and Nigeria; under Hormuz escalation it trims Kazakhstan and Libya, which are positively correlated with the Middle East factor, and adds Nigerian crude. Under compound stress, re-optimisation lowers CVaR from USD 77.13 to USD 75.89 per barrel. The Red Sea regime changes little because the baseline portfolio already avoids Red Sea routes.

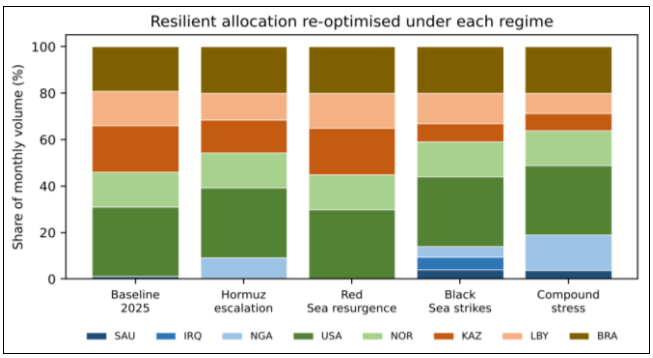

Fig 4: Recommended (S6) allocation re-optimised under each regime

5.7 Sensitivity analysis

Supply-security floor: Table 10 varies S_{min}. Floors up to 7.0 are not binding. Raising the floor to 7.5 replaces Libyan barrels with WTI; at 8.0 Libya leaves the portfolio and Saudi crude enters; at 8.25 Kazakhstan is also cut back. Each step costs more per unit of security than the last, which gives the committee a menu of explicit prices for security.

Table 10: Effect of the supply-security floor (λ = 0.5, baseline regime)

S_{min}	SAU	IRQ	NGA	USA	NOR	KAZ	LBY	BRA	E[cost]	CVaR 95%
6.50	0	1.7	0.5	22.9	15.0	20.0	20.0	20.0	71.37	73.03
7.00	0	1.7	0.5	22.9	15.0	20.0	20.0	20.0	71.37	73.03
7.50	0	0	0	30.0	15.0	20.0	15.0	20.0	71.44	73.07
8.00	15.0	0	0	30.0	15.0	20.0	0	20.0	71.68	73.26
8.25	25.7	0	0	30.0	15.0	9.3	0	20.0	72.02	73.67

Chokepoint and lead-time limits: Table 11 tightens the chokepoint cap and adds a lead-time ceiling. A 15% cap on each chokepoint group forces Kazakhstan down to 15% and spreads volume across more suppliers at a cost of about USD 0.12 per barrel; a 5% cap costs USD 0.41. Shortening the average voyage below 13.5 days is possible only by replacing Brazilian volume with Saudi crude, and combinations of a strict chokepoint cap with a short lead time are infeasible under the security floor. This is a genuine trade-off for a Mediterranean buyer: the most secure barrels come from far away.

Table 11: Effect of chokepoint caps and lead-time ceilings (S_{min} = 7.5, λ = 0.5)

Chokepoint cap	L_{max} (days)	Allocation (% of volume)	E[cost]	CVaR 95%	Avg. lead
5.0%	none	USA 27.2%, BRA 20.0%, LBY 19.4%, NOR 15.0%, SAU 5.0%, KAZ 5.0%, IRQ 4.7%, NGA 3.7%	71.85	73.31	15.0
5.0%	13.5	Infeasible	-	-	-
5.0%	13.0	Infeasible	-	-	-
15.0%	none	USA 28.3%, BRA 20.0%, LBY 17.3%, NOR 15.0%, KAZ 15.0%, SAU 3.5%, IRQ 1.0%	71.56	73.09	13.9
15.0%	13.5	USA 30.0%, LBY 18.2%, BRA 18.0%, NOR 15.0%, KAZ 15.0%, SAU 3.8%	71.55	73.11	13.5
15.0%	13.0	USA 30.0%, LBY 17.1%, NOR 15.0%, KAZ 15.0%, SAU 12.5%, BRA 10.5%	71.58	73.18	13.0
35.0%	none	USA 30.0%, KAZ 20.0%, BRA 20.0%, NOR 15.0%, LBY 15.0%	71.44	73.07	13.7
35.0%	13.5	USA 30.0%, KAZ 20.0%, BRA 17.0%, NOR 15.0%, LBY 14.5%, SAU 3.5%	71.45	73.08	13.5
35.0%	13.0	USA 30.0%, KAZ 20.0%, NOR 15.0%, LBY 13.4%, SAU 12.1%, BRA 9.5%	71.49	73.15	13.0

Ranking robustness: Fig 5 varies the AHP weight on supply security from 0.10 to 0.70, rescaling the other weights proportionally. Norway, the United States and Brazil hold the top three ranks throughout, and Iraq stays in the bottom three. The middle of the ranking is less stable: Libya ranks fourth when security carries little weight, because it is cheap and close, and falls to the bottom when security dominates. Tier assignments for the strategic core are therefore robust, while the flexible and opportunistic tiers should be reviewed whenever the committee's priorities shift.

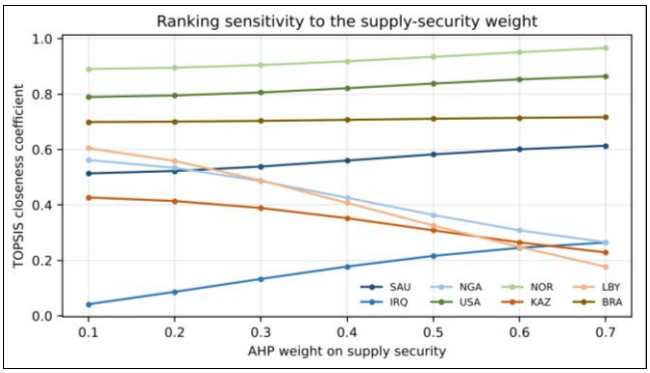

Fig 5: TOPSIS closeness coefficients as the weight on supply security varies

6. Discussion

6.1 Ranking and allocation answer different questions

The clearest lesson of the case is the gap between the TOPSIS ranking and the optimal allocation. Libya and Kazakhstan rank sixth and seventh, yet the recommended portfolio fills Kazakhstan to its cap and still takes 15% of its volume from Libya. This is not a contradiction. A ranking compares suppliers one at a time; an allocation compares portfolios, and a portfolio can carry a discounted, risky source safely if the rest of the mix is uncorrelated with it and the share is capped. Conversely, a well-ranked supplier such as Saudi Arabia receives no baseline volume because its Red Sea exposure adds correlated risk without a compensating discount. Procurement committees that translate rankings directly into volumes, as the TOPSIS-proportional rule does, overpay.

The two stages are nevertheless complementary. The recommended portfolio places 65.0% of volume with strategic-core suppliers and limits opportunistic-tier suppliers to the remainder, which is a natural governance rule consistent with supplier relationship management practice (Akinleye and Adeyoyin, 2022b): core suppliers on term contracts, flexible and opportunistic suppliers on frame agreements or spot.

6.2 The cost of resilience

In the baseline regime the recommended portfolio costs about 0.07 USD per barrel more than the cost minimiser, roughly 0.10% of delivered cost. In return it removes Hormuz exposure, lifts the security score by more than one point and cuts compound-stress tail cost by more than USD 4 per barrel. Viewed as an insurance contract, and evaluated with the same discipline as any analytics-based capital allocation decision (Lawal and Oduleye, 2021a), the annual premium of about USD 5.4 million buys protection worth about USD 26.8 million in a single bad month. This ratio is favourable even if severe months are rare, which explains why heuristic rules that buy resilience indiscriminately look expensive by comparison. Treating the premium as a budgeted line item, subject to the same cost governance and capital-efficiency tests as other spending (Walawalkar *et al*., 2025; Adesuyi *et al*., 2023; Oduleye and Medon, 2021), and hedging the currency exposure of multi-origin purchases through treasury policy (Dada *et al*., 2021), keeps the choice transparent to finance committees.

6.3 Evidence on the propositions

The results are consistent with all four propositions of Section 3. Concentration on correlated Middle East and Black Sea routes raised CVaR far more than expected cost, the TOPSIS ranking and the optimal allocation diverged for discounted suppliers, most of the resilience benefit came from the security floor and chokepoint caps rather than from the risk-aversion parameter, and re-optimisation reduced tail cost in every stress regime. These findings rest on a stylised case, and Section 8 sets out the conditions under which they may not hold.

7. Implications

7.1 Managerial implications

Because re-optimised portfolios outperform fixed ones in every stress regime, the model supports simple trigger rules that a trading desk can apply without re-running the full analysis each day, consistent with predictive procurement planning and vendor risk monitoring (Okonkwo *et al*., 2024c; Tonoyan *et al*., 2024a):

- **Hormuz trigger:** If war-risk premiums for Gulf loadings double or daily Hormuz transits fall by more than 20%, suspend new Basrah spot purchases and shift up to 10% of volume from Kazakhstan and Libya toward West African or Atlantic grades.
- **Red Sea trigger:** If Joint War Committee listings expand or a merchant vessel is struck, re-route Yanbu cargoes around the Cape or replace them with Atlantic barrels, and treat Saudi volume as flexible rather than core.
- **Black Sea trigger:** After any strike on CPC or Novorossiysk infrastructure, cap Kazakhstan at about 8% until loadings normalise, since mooring and export equipment repairs take time (Obetta and Ninduwezuor-Ehiobu, 2019; Obetta *et al*., 2020), and pre-book replacement WTI or Brazilian cargoes.
- **Compound trigger:** If two of the above fire within a month, move to the compound-stress allocation, raise the share of the strategic core to at least 65% and draw on commercial inventory to cover the longer Atlantic voyages (Okonkwo *et al*., 2018b; Okonkwo *et al*., 2023b).

7.2 Policy implications

For governments and national oil companies, the results suggest that diversification policy should target correlated exposure rather than the number of suppliers alone. Import security indicators that weight suppliers by political risk (Le Coq and Paltseva, 2009; Yang *et al*., 2014) could be complemented by measures of shared chokepoint and corridor exposure. Strategic reserves are most valuable in the compound regimes that drive tail cost (Teisberg, 1981; Chen *et al*., 2014), so stock policy and procurement policy

should be coordinated. Sanctions and export-control regimes change the feasible supplier set quickly, which argues for compliance screening that is integrated into procurement rather than applied after contracts are signed (Jones and Ominyi, 2023; Aneke and Adesemoye, 2021). Regional cooperation on maritime security and on terminal protection reduces the probability terms that dominate the tail (Notteboom *et al*., 2024; Liadi, 2024).

7.3 Theoretical implications

The study shows how a committee-facing multi-criteria screen and a risk-averse allocation model can be combined without double counting, by using the screen for tiering and the optimisation for volumes. It also illustrates that, for supply portfolios exposed to geopolitical risk, the dependence structure of disruptions matters as much as their marginal probabilities, which links the energy security literature on diversification indices (Cohen *et al*., 2011; Vivoda, 2009) with the operations literature on CVaR-based supplier portfolios (Sawik, 2011; Sawik, 2013). Finally, it frames resilience as a priced choice whose cost can be read directly from the efficient frontier, giving a concrete meaning to the trade-off discussed conceptually in the resilience literature (Pettit *et al*., 2010; Kamalahmadi and Parast, 2016).

8. Limitations

The numerical case is stylised. Differentials, freight, probabilities and security scores are calibrated to the 2025 environment for illustration and should be replaced with a firm's own quotes, contract terms and intelligence before use. Crude quality is captured only through the differential, whereas a refinery's yield and its sulphur and acidity limits create non-linear blending constraints that a linear programme can include only approximately. The model is single-period and does not represent inventory dynamics or term-contract nomination windows (Okonkwo *et al*., 2021a). Disruption probabilities are judgemental, and the copula correlations are assumptions rather than estimates. Sanctions compliance, which in 2025 involved tightening measures against Russian oil trade, is treated as a score rather than a hard eligibility rule; in practice some suppliers or vessels would be excluded outright under compliance frameworks for procurement in high-risk energy environments (Okonkwo *et al*., 2021b; Jones and Ominyi, 2023). Finally, the stress regimes are calibrated to a small number of observed events, and the compound regime is hypothetical.

9. Future Research

Several extensions follow directly. A multi-stage stochastic version with inventory, nomination windows and freight contracting would show how quickly a portfolio can actually be moved (Birge and Louveaux, 2011; Okonkwo *et al*., 2025). Disruption probabilities and correlations could be estimated and updated with Bayesian methods from incident data and news-based geopolitical risk indices (Caldara and Iacoviello, 2022; Mignon and Saadaoui, 2024), and robust optimisation offers an alternative when such estimates are unreliable (Bertsimas and Sim, 2004; Bertsimas *et al*., 2011). Integrating refinery yield and blending models would capture crude-quality effects (Neiro and Pinto, 2004; Pongsakdi *et al*., 2006). Further work could add cyber-physical disruption of pipelines and terminals (Adegbite *et al*., 2025; Amadi *et al*., 2025), ESG and emissions criteria in supplier choice (Ike *et al*., 2025; Abioye *et al*., 2023), and the long-run effect of the energy transition on the supplier set (Komi, 2025). Empirical validation with procurement data from refiners in importing regions, including West Africa and Asia, would test whether the propositions hold beyond the stylised case.

10. Conclusion

Geopolitical risk in 2025 did not show up as a general oil shortage. It showed up as route-specific, partly correlated disruptions that punished buyers who had optimised for price alone. This paper has proposed a decision model that compares alternative suppliers across purchase cost, transport risk, lead time and supply security, and converts that comparison into a volume plan. AHP captures the committee's priorities, TOPSIS ranks and tiers suppliers, and a scenario-based mean and CVaR linear programme allocates volume under contractual, chokepoint, lead-time and security constraints.

For the illustrative Mediterranean refinery, the recommended portfolio costs about USD 0.07 per barrel more than a pure cost minimiser in normal months but reduces tail cost by about USD 4.47 per barrel in a compound crisis, and dominates both single sourcing and simple diversification rules. Three practical conclusions follow: rankings should inform contract tiers rather than volumes; resilience should be purchased through explicit constraints whose price can be seen and debated; and pre-agreed triggers that move the portfolio when a regime changes add meaningful protection at little cost. The framework is transparent, solvable with standard tools, and can be refreshed every month as the geopolitical picture evolves, ideally embedded in the integrated digital procurement systems that energy buyers already use.

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