



The Energy Transition Paradox: Stranded Asset Risk and Strategic Resilience in the GCC

Oil and Gas Sector

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Abstract

The global commitment to net-zero emissions is in direct tension with the continued capacity expansion of Gulf Cooperation Council (GCC) national oil companies (NOCs). Between 2024 and 2030, Saudi Aramco, the Abu Dhabi National Oil Company (ADNOC), and QatarEnergy are each pursuing production or export capacity increases even as multilateral climate commitments call for a peak and decline in fossil fuel demand. This thesis examines that tension, which it calls the Energy Transition Paradox, as it applies specifically to state-backed, low-cost GCC producers, a population that existing stranded-asset scholarship has largely left unexamined in favor of higher-cost, investor-owned international oil companies (IOCs). Using Real Options Theory as an analytical lens, informed by rentier state theory's account of GCC political economy, and a mixed-methods design combining scenario-based financial exposure modeling with a comparative case study of Aramco, ADNOC, and QatarEnergy, the thesis argues that GCC NOCs are pursuing a dual strategy: monetizing reserves ahead of anticipated demand decline while simultaneously investing in carbon capture, crude-to-chemicals conversion, and blue hydrogen/ammonia export infrastructure to preserve strategic optionality. An illustrative scenario-based exposure model finds that estimated 25-year reserve margin value for Saudi Aramco could range from approximately \$2.1 trillion under a Net Zero Emissions pathway to \$3.4 trillion under a Current Policies pathway, a swing of roughly one-third, with a proportionally larger swing for ADNOC that reflects its thinner, less-disclosed cost margin. The analysis further identifies a capital-allocation mechanism specific to RQ3 that has received little attention in the literature to date: GCC NOCs increasingly raise external capital by listing minority stakes in subsidiaries, including Aramco's 2019 and 2024 share offerings and ADNOC's serial listings of ADNOC Gas, ADNOC Drilling, Borouge, and Fertigllobe, while retaining

majority control of the core reserve base. This mechanism effectively monetizes a slice of future cash flow without surrendering the underlying real option. ADNOC's 2024 launch of XRG, an \$80-billion international investment vehicle that deploys capital abroad rather than domestically, extends this capital-allocation pattern in a further direction and complicates the boundary this thesis otherwise draws between NOC and sovereign wealth fund capital allocation. The thesis concludes with capital-allocation recommendations for NOC boards and a discussion of the sovereign-level fiscal implications of stranded-asset risk, while explicitly acknowledging the limitation that GCC NOCs do not disclose reserve valuations with the granularity available for publicly listed IOCs, and that the exposure model presented is illustrative rather than an audited valuation.

Keywords: stranded assets, energy transition, GCC, national oil companies, real options theory, rentier state, strategic resilience, capital allocation

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List of Abbreviations

ADNOC	Abu Dhabi National Oil Company
CBAM	Carbon Border Adjustment Mechanism (European Union)
CCUS	Carbon Capture, Utilization, and Storage
COP28	28th Conference of the Parties to the UN Framework Convention on Climate Change
CTC	Crude-to-Chemicals (conversion technology)
DCF	Discounted Cash Flow
EIA	U.S. Energy Information Administration
GCC	Gulf Cooperation Council
IEA	International Energy Agency
IOC	International Oil Company
IPO	Initial Public Offering
IRENA	International Renewable Energy Agency
LNG	Liquefied Natural Gas
MTPA	Million Tonnes Per Annum
NOC	National Oil Company
NPV	Net Present Value
NZE	Net Zero Emissions by 2050 (IEA scenario)
OPEC+	Organization of the Petroleum Exporting Countries and allied non-OPEC producers
PIF	Public Investment Fund (Saudi Arabia)
RQ	Research Question
STEPS	Stated Policies Scenario (IEA)
SWF	Sovereign Wealth Fund
TCFD	Task Force on Climate-related Financial Disclosures
VRIN	Valuable, Rare, Imperfectly imitable, Non-substitutable (Barney's resource criteria)

Chapter 1: Introduction

1.1 Background

The 2015 Paris Agreement, and the consensus reached at COP28 in Dubai, which for the first time named a transition “away from fossil fuels in energy systems” as a shared global objective, turned the trajectory of fossil fuel demand into a matter of formal multilateral commitment. The claim that no new long-lead-time oil and gas fields are required under a pathway consistent with net zero emissions by 2050 originates in the IEA's landmark Net Zero by 2050 report (IEA, 2021); each subsequent World Energy Outlook has carried the claim forward with updated figures. The IEA's World Energy Outlook 2025 frames this trajectory across three scenarios that diverge sharply for oil producers. Under the Net Zero Emissions by 2050 (NZE) Scenario, no new long-lead-time oil and gas fields are required and some existing fields close early. Under the Current Policies Scenario, oil demand keeps rising, to as much as 113 million barrels per day by 2050, driven by petrochemical feedstock demand and transport growth in emerging economies (IEA, 2025b). For a hydrocarbon exporter, the distance between these two paths is the distance between a stable revenue base and a multi-decade write-down.

The multilateral consensus behind that 2050 pathway has not held steady since COP28. At COP29 in Baku in November 2024, countries agreed to triple the developed-country climate finance goal, to \$300 billion annually by 2035, but the fossil-fuel-transition pledge itself went unmentioned, deferred to COP30 (UN News, 2024). COP30 in Belém, in November 2025, fared no better on that specific point: more than 80 countries backed a formal roadmap for a fossil fuel phase-out, and the language was stripped from the final text in the closing hours of talks. The agreed text fell back on the existing COP28 wording, and COP30's president announced plans to draft a transition roadmap as a future initiative outside the conference decision (UN News,

2025). Two COPs running, the finance and adaptation architecture of the Paris Agreement has advanced while the fossil-fuel-transition commitment itself has stalled. A GCC NOC weighing the credibility and timing of future climate policy, the judgment Section 2.2's Green Paradox discussion turns on, has reasonable grounds to weight the Current Policies trajectory more heavily than COP28's rhetoric alone would suggest.

For the Gulf Cooperation Council (GCC) states (Saudi Arabia, the United Arab Emirates, Qatar, Kuwait, Bahrain, and Oman), this uncertainty lands on economies still structurally dependent on hydrocarbon rents to fund sovereign budgets, public sector employment, and, increasingly, the diversification programs meant to reduce that same dependence. The paradox shows up in real time, in the investment decisions GCC national oil companies (NOCs) are making today. ADNOC has moved its production capacity target of 5 million barrels per day from an original 2030 deadline to 2027, backed by a \$150 billion capital expenditure program (OilPrice.com, 2026; Institute for Energy Research, 2026). QatarEnergy is executing what is described as the largest liquefied natural gas expansion program in the industry's history, lifting capacity from 77 to 142 million tonnes per annum by 2030 across three sequential North Field phases, on the back of a newly confirmed gas reserve addition of 240 trillion cubic feet (Offshore Technology, 2026). Saudi Aramco holds approximately 267 to 270 billion barrels of proven reserves, roughly 15% of the global total, and operates at production costs reported as low as \$2.8 to \$3.00 per barrel: a cost position that keeps the company profitable at price levels that would be ruinous for most global producers (Arab News, 2019).

Each of these three firms is also investing materially in the technologies most associated with decarbonization: carbon capture, crude-to-chemicals conversion that displaces combustion demand with materials demand, and blue hydrogen and ammonia export infrastructure aimed at

Asian and European buyers. GCC NOCs are not ignoring the energy transition. The paradox is that they are expanding hydrocarbon capacity and building a post-hydrocarbon hedge at the same time, with a scale of capital that only reserves of this size and cost position can support. They are also, less visibly, converting a slice of that hydrocarbon capital into external, publicly raised capital, a fourth pillar of the paradox alongside decarbonization technology, capacity monetization, and sovereign wealth diversification, taken up in Chapter 6.

1.2 Problem Statement

The academic and financial concept of “stranded assets,” meaning fossil fuel reserves, infrastructure, or capital that lose economic value before the end of their planned operating life because of changing climate policy, technology cost curves, or demand patterns, has developed substantially since the term moved from environmental advocacy into mainstream financial analysis (Daumas, 2024). Yet the empirical and theoretical center of gravity of this literature has remained fixed on a specific population: publicly listed, higher-cost, investor-owned international oil companies (IOCs) operating primarily in the North Sea, North America, and other high-cost basins, whose reserves are the first economically threatened by declining demand and rising carbon prices (Atanasova & Schwartz, 2020; Daumas, 2024; Coffin & Grant, 2020).

GCC NOCs occupy a structurally different position, one this literature has not adequately theorized. Sitting at the low-cost end of the global production cost curve puts them, on a pure economics basis, among the last reserves likely to be stranded by demand decline: a dynamic industry commentary calls “last barrel standing.” Their state ownership changes the calculus around write-downs, disclosure incentives, and the political tolerance for continued production even at declining margins. These companies are also the primary vehicle through which GCC sovereigns fund economic diversification away from hydrocarbons, which makes the capital at

risk of stranding fiscal and national as much as corporate. This last feature connects the stranded-asset question to an older body of political-economy scholarship on rentier states, introduced in Chapter 2, a necessary complement to the financial framing of stranding.

The scale of this risk is under-examined on two fronts. First, there is a physical and infrastructural risk: upstream and midstream capacity being built or expanded today, including new production capacity, new LNG trains, and new export pipelines, may face a shorter effective operating life than its capital planning assumes if global demand peaks and declines faster than the Current Policies trajectory implies. Second, there is a reserve valuation risk: the enormous proven reserve base that underpins GCC sovereign wealth and state budget planning may be systematically overvalued if a material share of it becomes uneconomic to extract under more aggressive climate policy or demand scenarios, even though these reserves are cheap to produce in absolute terms.

1.3 Research Questions

This thesis is organized around three research questions:

RQ1. Under the IEA's Stated Policies, Announced Pledges, and Net Zero Emissions scenarios, how does the financial exposure of GCC NOC reserves compare to that of higher-cost Western IOCs, and what accounts for the difference?

RQ2. What strategic-resilience mechanisms (carbon capture and utilization, crude-to-chemicals conversion, blue hydrogen and ammonia export infrastructure, and accelerated capacity monetization) are GCC NOCs deploying, and how does each mechanism map onto a specific transition-risk vector?

RQ3. How does the tension between near-term reserve monetization and long-term stranding risk manifest in the capital allocation decisions of GCC NOCs and their affiliated sovereign wealth funds?

RQ1 asks a comparative-magnitude question, and Chapter 4 answers it with the scenario-based discounted cash flow model developed in Section 3.4, which produces a directly comparable, dollar-denominated exposure estimate for GCC NOCs and an IOC benchmark across three IEA demand scenarios. The remaining two questions turn on strategic behavior rather than magnitude, a distinction that shapes how the thesis approaches them. Chapter 5 takes up RQ2 through a qualitative comparative case study, mapping each company's disclosed strategic-resilience investment onto the risk-vector taxonomy Chapter 4 develops, while Chapter 6 addresses RQ3 through a capital-allocation analysis that examines minority-stake listing activity, sovereign wealth fund portfolio composition, and the balance between monetization and diversification capital documented across Chapters 5 and 6. This division of labor is not incidental: quantification suits a comparative-magnitude question like RQ1, but it cannot on its own settle the kind of strategic-behavior questions RQ2 and RQ3 pose, which is why the mixed-methods design in Section 3.3 assigns quantitative and qualitative evidence to different questions rather than triangulating a single method across all three.

1.4 Scope and Limitations

This thesis focuses on upstream and midstream assets: reserves, production capacity, and export infrastructure, within Saudi Arabia, the United Arab Emirates, and Qatar, using Saudi Aramco, ADNOC, and QatarEnergy as the primary units of comparative analysis. Downstream retail operations are excluded to keep the analytical scope manageable; the stranded-asset

literature this thesis engages with is itself concentrated on upstream reserve and midstream infrastructure valuation, not retail distribution.

This thesis further distinguishes two tiers within that comparative scope, reflecting the different data environments the quantitative and qualitative phases draw on. The quantitative valuation scope, developed in Section 3.4 and applied in Chapter 4, is restricted to low-cost liquid crude reserves and comprises Saudi Aramco and ADNOC alongside ExxonMobil as an international oil company benchmark; QatarEnergy's asset base is predominantly natural gas rather than crude oil and is not commensurable with a per-barrel margin model without a separately sourced LNG price framework, a boundary specified further in Section 3.4. The qualitative strategic and capital-allocation scope, developed in Chapter 5 and Chapter 6, is broader: it encompasses integrated hydrocarbon and LNG producers, including QatarEnergy and international investment vehicles such as ADNOC's XRG, because the strategic-resilience and capital-allocation questions RQ2 and RQ3 pose do not depend on the crude-oil commensurability RQ1's exposure model requires. ExxonMobil's role in Section 4.6 follows the same logic in reverse: it enters the quantitative scope specifically to give RQ1 an IOC comparator on cost-curve grounds, not as a fourth case study within the qualitative scope developed in Chapter 5.

A related scope question concerns case selection within the GCC itself. Of the six GCC member states, this thesis selects Saudi Arabia, the UAE, and Qatar, and their respective national oil companies, and sets aside Kuwait, Bahrain, and Oman. The selection tracks reserve scale and market visibility. Saudi Arabia, the UAE, and Qatar together hold the substantial majority of GCC proven hydrocarbon reserves and account for the region's largest, most internationally visible capacity-expansion and capital-markets activity, the ADNOC and Aramco listings and the North Field expansion documented in Chapters 5 and 6 among them; this is what makes

sufficient public information available to support the secondary-source methodology described in Section 3.3. Kuwait's and Oman's national oil sectors are smaller in absolute reserve and production terms and have pursued less internationally documented capital-markets activity during this thesis's analysis window. Bahrain's hydrocarbon sector is smaller still and structurally distinct: a largely depleted domestic reserve base, not the low-cost abundance that defines this thesis's three cases. This is a limitation, not a finding. The strategic-resilience and capital-allocation patterns this thesis documents for Aramco, ADNOC, and QatarEnergy should not be assumed to generalize to the three excluded states without direct investigation.

GCC NOCs, unlike publicly listed IOCs, are not required to disclose reserve valuations, internal write-down assumptions, or asset-level financial exposure with the granularity available in, for example, SEC filings of US-listed oil majors, and this is the thesis's central methodological limitation. The scenario-based financial exposure modeling in Chapter 4 relies on secondary and estimated data: public reserve figures, IEA scenario assumptions, and third-party cost-curve analysis. The modeling establishes the order of magnitude and directional sensitivity of exposure under different scenarios; it does not produce audited valuation figures.

A second scope boundary sits apart from the upstream/downstream distinction above. Carney's (2015) foundational framing of climate-related financial risk, discussed further in Section 2.6, distinguishes transition risk, the risk this thesis analyzes throughout, from physical risk, the risk that a changing climate directly damages assets or disrupts operations, and liability risk, the risk of legal claims arising from climate-related harm. This thesis is concerned exclusively with transition risk. It does not model the physical climate risk GCC hydrocarbon infrastructure itself faces, and that risk is far from hypothetical for the region. Pal and Eltahir's (2016) regional climate modeling projects that extremes of wet-bulb temperature around the

Arabian Gulf are likely to approach or exceed the threshold of human survivability under a business-as-usual emissions pathway within this century, with direct implications for outdoor industrial operations, including the upstream and midstream facilities this thesis analyzes.

Physical risk and transition risk are conceptually independent. A facility can be transition-risk-insulated by virtue of low production cost while remaining physically exposed to extreme heat; a full climate-risk assessment of GCC hydrocarbon infrastructure would need to model both. The exclusive focus on transition risk here is a scope decision made for analytical tractability, not a claim that physical risk is immaterial.

1.5 Structure of the Thesis

Chapter 2 reviews the literature on stranded assets, the resource curse and rentier state traditions, and corporate strategic resilience, and positions this thesis's contribution within the resulting gap. Chapter 3 develops the Real Options theoretical framework and the mixed-methods research design, including the scenario-based exposure model used in Chapter 4. Chapter 4 takes up RQ1 directly, working through the cost-curve, policy, and technological risk vectors and the exposure model results. Chapter 5 turns to RQ2, through a risk-response matrix and three company case studies. Chapter 6 addresses RQ3 through capital allocation and capital markets strategy, together with sovereign-level implications, and draws findings together across all three research questions. Chapter 7 concludes.

Chapter 2: Literature Review

2.1 Deconstructing “Stranded Assets”

The term “stranded assets” originated largely within environmental and climate-advocacy analysis, most prominently in the “unburnable carbon” framing that compared proven global fossil fuel reserves against the remaining carbon budget consistent with limiting warming to 2°C. Over the past decade, however, the concept has migrated into mainstream financial economics, where it is now typically defined with reference to specific financial mechanisms rather than physical carbon-budget arithmetic: asset write-downs, impairment charges, devaluation of proven and probable reserves on company balance sheets, and repricing of debt and equity issued against those reserves as collateral or cash-flow expectation (Daumas, 2024).

Daumas's (2024) critical review in the *Journal of Economic Surveys* is instructive on this evolution. It traces how the stranded-asset concept has matured from a narrow focus on impaired physical assets to a broader framework encompassing stranded resources (reserves that will never be extracted), stranded capital (sunk investment in infrastructure), and stranded paper (financial claims, such as debt and equity, whose value depends on the future cash flows of those assets). The three categories carry different risk implications for GCC NOCs specifically. As state-owned, low-cost producers, GCC firms are comparatively insulated on the stranded resources dimension, since their reserves are, on cost grounds, unlikely to be the first left in the ground. They are more exposed on the stranded capital dimension, given the scale of new infrastructure, such as LNG trains, pipelines, and expanded production facilities, currently under construction with multi-decade payback assumptions.

Atanasova and Schwartz (2020), in a widely cited NBER working paper, model the relationship between disclosed reserve data and firm value for a sample of oil and gas

companies, finding that markets already price in some probability of reserves remaining undeveloped. Capital markets, in other words, already partially price stranded-asset risk into hydrocarbon reserve valuations. Their approach, using scenario-based valuation of reserves under alternative extraction assumptions, is methodologically relevant to the DCF-based scenario modeling adopted in Chapter 3, though their sample is drawn from publicly listed, primarily Western firms: the population gap this thesis addresses.

The applied-research and investor-advocacy literature offers a complementary, more project-level view. The Carbon Tracker Initiative, whose 2011 “Unburnable Carbon” report is credited with popularizing the concept for financial audiences, has since built a least-cost methodology for assessing individual project economics against IEA-derived demand pathways. Coffin and Grant (2020), in Carbon Tracker's Fault Lines report, apply this methodology to the fifteen largest oil and gas projects sanctioned in 2019 and find approximately \$60 billion of associated capital expenditure is not competitive under the IEA's climate-aligned demand scenarios. Chapter 4 returns to this project-level articulation of stranding risk as a cross-check against the scenario exposure estimates developed there.

The valuation architecture Chapter 3 formalizes as Real Options Theory has a direct precedent within the stranded-asset literature's own methodological lineage. Brennan and Schwartz's (1985) foundational analysis of natural resource investment, developed around a hypothetical copper mine, established that the value of an extractive asset depends not only on current commodity prices but on the option to accelerate, delay, or abandon extraction as prices and costs evolve, a framing this thesis extends in Chapter 3 from mine-level operating decisions to reserve-level stranding risk. On the physical-quantification side, McGlade and Ekins's (2015) widely cited Nature study estimates that meeting a 2°C warming limit requires roughly a third of

global oil reserves, half of gas reserves, and over 80% of coal reserves to remain unextracted, and finds that Middle East reserves, because of their low extraction cost, are disproportionately represented among the reserves that remain economically viable to produce even under a constrained carbon budget, a finding directly consistent with, and independently corroborating, the cost-curve argument this thesis develops in Section 4.1.

2.2 The Green Paradox: Anticipated Policy and the Incentive to Extract Faster

Sinn's (2008) Green Paradox argues that a climate policy which becomes credibly stricter over time functions, from a resource owner's perspective, as an announced future expropriation of the value of unextracted reserves. An anticipated future tightening of demand-side climate policy can rationally induce owners to extract and sell reserves faster today, before the tightening reduces their market value, an outcome exactly opposite to the policy's intended effect. Sinn's own proposed correction is a supply-side one: because resource owners respond to the credibility and timing of future constraints, not only to current-period demand-reduction measures, avoiding the paradox requires policy aimed at extraction itself, not only at consumption.

The Green Paradox offers an alternative reading of the capacity-acceleration behavior documented in Chapter 1. ADNOC's advancement of its production target from 2030 to 2027 and QatarEnergy's accelerated North Field build-out could be read as a cost-curve-protected “last barrel standing” strategy, or as a Green-Paradox-consistent response to anticipated future demand constraint, monetizing reserves before an anticipated tightening reduces their value. These two readings are not mutually exclusive, and adjudicating between them empirically would require evidence of GCC NOC management's internal beliefs about the credibility and timing of future climate policy that public sources do not provide. What the Green Paradox contributes is a caution against reading capacity acceleration as evidence against stranded-asset

concern. Under Sinn's (2008) logic, capacity acceleration is precisely the behavior a firm that takes future stranding risk seriously should be expected to exhibit, reinforcing rather than undermining the argument that GCC NOC behavior reflects a considered response to transition risk, not denial or unawareness of it.

The Green Paradox reading also complicates the OPEC+ market-management caveat developed in Section 4.4. If Saudi Arabia's and the UAE's production decisions are coordinated through quota policy rather than set by cost competition alone, the timing of any Green-Paradox-consistent acceleration is subject to a further layer of collective bargaining among producers with only partially aligned expectations about the credibility of future climate policy. A clean read of GCC production behavior through either the cost-curve lens of Section 4.1 or the Green Paradox lens developed here is accordingly harder than either framework alone would suggest.

The two frameworks are better read as a single synthesized model than as competing explanations for a single behavior. This thesis terms that synthesis the Dual-Mechanism Rentier Adaptation Model: Sinn's (2008) Green Paradox governs the upstream depletion trajectory, the pace at which GCC NOCs pull proven, low-cost reserve volumes out of the ground ahead of anticipated demand destruction, while Real Options Theory, developed formally in Chapter 3, governs a separate lever, downstream and midstream capital reinvestment, the pace and scale at which current cash flow is redeployed into CCUS, blue ammonia, and crude-to-chemicals switching options that preserve terminal asset value. The two mechanisms operate on different sides of the same balance sheet rather than on the same decision: the Green Paradox explains why reserves move out of the ground faster, and Real Options Theory explains where the cash those reserves generate is then redeployed. Chapter 1's fourfold paradox, capacity expansion, decarbonization technology, capacity monetization, and capital-markets diversification, is the

empirical signature of this dual mechanism: capacity expansion and monetization are Green-Paradox-consistent depletion behavior, while decarbonization technology investment and, examined in Chapter 6, capital-markets diversification are Real-Options-consistent reinvestment behavior. Section 6.1 returns to this model directly once Chapters 4 and 5 have established the empirical record it organizes.

2.3 The Energy Transition Paradox: Resource Curse, Rentier State Theory, and Brown-to-Green Financing

The tension this thesis calls the Energy Transition Paradox connects to several older strands of resource-economics and political-economy literature. The first is the resource curse literature, originating with Sachs and Warner's (1995, 2001) empirical finding that economies with high natural-resource export dependence tended to exhibit slower long-run growth than resource-poor economies, even after controlling for other growth determinants. They attributed this to mechanisms including currency appreciation effects on non-resource tradables, weaker incentives for institutional development, and volatility in resource-linked revenue. GCC states have, in absolute terms, converted resource wealth into some of the highest per-capita income levels globally, a divergence from the classic resource curse growth-rate finding, but the underlying structural dependence on a single, climate-exposed revenue source remains the operative vulnerability this thesis is concerned with, independent of whether it has historically suppressed growth rates.

The second, and arguably more directly applicable, strand is rentier state theory, developed by Beblawi and Luciani (1987) specifically with reference to the Arab Gulf states. Beblawi and Luciani characterize a rentier state as one in which a substantial share of national income derives from external rent, historically hydrocarbon export revenue, rather than from

domestic productive activity or taxation. The effect is to decouple the state's fiscal position from its citizens' economic output and, in their analysis, from the political accountability that typically accompanies taxation. This thesis does not adopt the political dimensions of rentier state theory as a research object in their own right, but it borrows the theory's core structural insight: in a rentier economy, a shock to the rent stream is a state-level fiscal event, not merely a corporate balance-sheet one. This is precisely the mechanism that elevates GCC stranded-asset risk from a question of firm valuation, the frame dominant in the IOC-focused literature reviewed above, to a question of sovereign fiscal exposure, and it directly motivates this thesis's decision, formalized in Chapter 6, to treat sovereign wealth fund capital allocation as inseparable from NOC capital allocation rather than as a separate topic.

Beblawi and Luciani's (1987) framing itself builds on Mahdavy's (1970) earlier coinage of the term “rentier state” in his study of Iran's oil-based economy, which first identified external rent, rather than domestic production or taxation, as the structural feature reorganizing a state's relationship to its economy and citizens. Subsequent large-N cross-national scholarship has substantially extended this foundational insight. Karl's (1997) comparative study of oil-booming states, including Venezuela, Iran, Nigeria, Algeria, and Indonesia, traces how petrodollar windfalls in the 1970s reshaped state institutions toward patronage-based, centralized spending patterns that persisted long after the windfalls themselves receded, weakening the very state capacity needed to manage a future transition away from oil dependence. Ross's (2012) subsequent quantitative work operationalizes and tests three specific rentier mechanisms, a rentier effect (low taxation dampening democratic accountability), a repression effect, and a modernization effect, and finds statistically fragile but directionally consistent support for the rentier effect specifically across a large cross-national panel. Ross's qualification that empirical

support for these mechanisms is real but fragile is a useful caution against overstating rentier state theory's explanatory reach in this thesis's own application of it: the theory is borrowed here, as stated above, for its structural insight into the sovereign-corporate entanglement of hydrocarbon revenue, not as a fully validated causal account of GCC political development, which remains contested in the broader literature this thesis does not attempt to resolve.

The third, more recent strand is the “brown-to-green financing” literature examining how hydrocarbon-dependent economies are using current fossil fuel revenue to fund the diversification intended to reduce future dependence on that same revenue. This is the paradox at its clearest: the capital required to build a Saudi, Emirati, or Qatari economy less exposed to stranded-asset risk comes from maximizing near-term extraction and monetization of the assets most exposed to that risk. Read through rentier state theory, this is close to a structural necessity rather than an incidental policy choice, since the state's fiscal base is the rent stream itself. Financing diversification from any other source would require the domestic taxation or productive-sector development that rentier economies, by Beblawi and Luciani's (1987) own account, are poorly positioned to build quickly. The dynamic is visible directly in sovereign wealth fund capital flows, discussed further in Chapter 6.

2.4 Strategic Resilience in Energy: Corporate Adaptation Under Disruption

A separate literature addresses how incumbent firms in a legacy industry respond to a disruptive technological or regulatory shift that threatens the core of their business model. Two frameworks recur in this literature and are evaluated formally against Real Options Theory in Chapter 3. Barney's (1991) Resource-Based View holds that sustained competitive advantage derives from resources and capabilities that are valuable, rare, imperfectly imitable, and non-substitutable, the VRIN criteria. This lens explains why GCC NOCs, holding a resource in low-

cost reserves that is difficult for competitors to replicate, retain a durable strategic advantage, but it does not by itself model how a firm should time or size a specific hedging investment under uncertainty. Teece, Pisano, and Shuen's (1997) Dynamic Capabilities framework goes further, defining a firm's capacity to adapt, integrate, and reconfigure internal and external resources to match a changing environment. It is a better fit for describing organizational adaptation broadly, but it is similarly under-specified on the quantitative, option-value question of when a specific real-world hedge, such as a CCUS investment or a blue ammonia plant, is worth making relative to its cost.

Applied to energy specifically, this literature generally identifies a spectrum of firm responses to disruption ranging from denial and lobbying-based resistance, through diversification and portfolio hedging, to wholesale business-model transformation. GCC NOCs occupy a distinctive position on this spectrum, argued in Chapters 4 and 5. Their core low-cost hydrocarbon business remains commercially viable for longer than higher-cost peers, giving them the balance-sheet capacity to pursue diversification and hedging strategies, such as crude-to-chemicals, blue hydrogen, and carbon capture, funded by continued core-business cash flow. Some higher-cost Western producers, by contrast, are increasingly forced into transformation by an already-collapsing core business.

2.5 GCC-Specific Energy Transition Literature

A fifth, adjacent literature engages the Gulf energy transition directly, without adopting a stranded-asset valuation lens. Sanfilippo, Vermeersch, and Benito (2024), writing in *Energy Strategy Reviews*, document GCC energy transition strategies since COP26, centered on solar photovoltaic deployment alongside emerging technologies including energy storage and carbon capture, against a backdrop of GCC consumption-based carbon dioxide emissions that roughly

doubled between 2003 and 2020. The International Renewable Energy Agency's GCC market report similarly documents the scale of the region's renewables build-out, with installed capacity rising from 176 megawatts in 2013 to over 5.6 gigawatts by 2022, and projects substantial employment gains from continued solar deployment (IRENA, 2023).

This literature is valuable background for Chapters 5 and 6 but does not substitute for the gap this thesis addresses. It documents the pace and scale of GCC renewable and decarbonization investment; it does not connect that investment to reserve-level stranded-asset exposure, to Real Options Theory, or to the capital-allocation mechanisms examined in Chapter 6. Where Sanfilippo et al. (2024) and IRENA (2023) establish that GCC states are diversifying their energy mix at meaningful scale, this thesis asks a narrower and different question: what that diversification implies for the financial exposure and capital-allocation logic of the hydrocarbon-producing NOCs that are funding it.

2.6 Financial Regulation and the Mainstreaming of Climate Risk

A sixth, adjacent development explains why the stranded-asset concept has acquired practical urgency for corporate disclosure and investor decision-making beyond its academic origins. Carney's (2015) “Tragedy of the Horizon” speech, delivered as Governor of the Bank of England and Chair of the Financial Stability Board, identified stranded-asset risk specifically as a financial stability concern: because the catastrophic costs of climate change fall outside the time horizons that typically discipline financial market behavior, a system that prices climate-related risk only when it becomes imminent, rather than when it becomes foreseeable, systematically underprices transition risk until a disorderly repricing event forces a correction. Carney's proposed remedy, better and more consistent disclosure of climate-related financial risk, led directly to the creation of the Task Force on Climate-related Financial Disclosures, whose 2017

recommendations established governance, strategy, risk management, and metrics-and-targets as the four disclosure pillars now widely adopted, voluntarily and increasingly by regulatory mandate, across jurisdictions representing close to 60% of global GDP (TCFD, 2017).

This regulatory trajectory bears directly on this thesis's central methodological limitation, stated in Section 3.5 and again in Chapter 7: GCC NOCs currently disclose reserve valuation and cost data at a level of granularity well below what TCFD-aligned disclosure, now standard or emerging practice for SEC-registered and many exchange-listed IOCs, would require. This is not a coincidence but a structural consequence of ownership form: state-owned NOCs face no equivalent investor-driven disclosure pressure unless and until they access public capital markets, which is precisely why the minority-stake listing mechanism examined in Section 6.3 carries a disclosure dimension beyond its capital-raising function. As ADNOC's and Aramco's public-market exposure grows through the listings documented in Chapter 5 and Chapter 6, the TCFD-style disclosure expectations attached to that market access may, over time, generate exactly the reserve-level data this thesis's own quantitative phase was structurally unable to access, a possibility already flagged as an avenue for future research in Section 7.3 and made more concrete here by naming the specific disclosure framework, TCFD, through which that data would most likely first become available.

2.7 The Research Gap

Stranded-asset scholarship remains concentrated on higher-cost, investor-owned IOCs. Heras and Gupta's (2024) systematic literature review in *WIREs Climate Change*, covering scholarship on fossil fuels, stranded assets, and the energy transition in the Global South, provides partial confirmation of a gap relevant to this thesis. They find that existing literature on “leaving fossil fuels underground” in Global South contexts is limited, concentrated mainly on

subsidy politics rather than stranded-asset valuation specifically, and largely overlooks the distributive and power-dynamic dimensions of stranded-resource risk from a developing-country perspective.

This finding needs qualification before it can serve as this thesis's gap claim. GCC states are atypical members of any “Global South” categorization: high-income, capital-exporting economies whose sovereign wealth funds are themselves significant investors in the Global North, not capital-constrained developing economies. Heras and Gupta's (2024) gap is necessarily broader and differently motivated than the gap this thesis addresses. The GCC-specific energy policy literature, represented in this review by Fattouh's (2021) analysis of Saudi oil policy continuity and change for the Oxford Institute for Energy Studies, engages closely with GCC producer strategy and market-share behavior, but it is oriented toward oil-market and OPEC+ policy dynamics, not stranded-asset valuation or firm-level real-options framing.

The more precise gap, at the intersection of these literatures, is this. Stranded-asset literature has theorized extensively about high-cost, shareholder-accountable, disclosure-regulated IOCs (Atanasova & Schwartz, 2020; Daumas, 2024; Coffin & Grant, 2020). GCC energy-policy literature has theorized extensively about GCC producer market-share and pricing behavior (Fattouh, 2021) without a stranded-asset valuation lens. Global South literature has theorized about fossil fuel dependence and justice in capital-constrained developing economies (Heras & Gupta, 2024) in a frame that does not fit high-income GCC states. No existing strand combines a stranded-asset valuation framework with the specific combination of characteristics GCC NOCs present: low-cost, state-owned, high-income, rentier-structured, and simultaneously the primary financing vehicle for post-hydrocarbon economic diversification. This thesis positions itself in that narrower, more specific space.

2.8 Exogenous Volatility: Quota Mechanics and Geopolitics in Extractive Strategy

The literatures reviewed above largely treat GCC production and investment decisions as though they were the output of a single firm optimizing against cost curves and climate-policy uncertainty. Two further sources of variation sit outside that frame and are best introduced theoretically before Chapters 4 and 5 apply them empirically: coordinated volume management among OPEC+ members, and acute geopolitical or physical disruption to production and export infrastructure.

OPEC+ quota coordination is usefully modeled as an administered volume constraint rather than as a market outcome: a collectively negotiated ceiling on production that can bind tighter or looser than pure marginal-cost competition would produce on its own, with Saudi Arabia's role as the group's swing producer, holding on the order of 60% of global spare capacity, the clearest instance of this administered mechanism in practice (Finley, 2024). Where the cost-curve logic of Section 4.1 predicts that low-cost reserves should be produced up to the limit of demand, quota coordination can override that prediction in either direction, restraining production below the cost-competitive level to defend price, or, as the swing-producer role itself illustrates, holding capacity in reserve rather than deploying it. This distinction matters for how the Real Options framework adopted in Chapter 3 is applied: a firm's decision to exercise a production option is ordinarily a function of price and cost alone, but for a quota-constrained producer it is additionally a function of a negotiated ceiling that neither the firm nor a purely economic model of its behavior fully controls.

Acute geopolitical and physical shocks, infrastructure attacks, chokepoint disruption, and comparable events, operate on a different axis again. Where quota coordination is a slow-moving, negotiated constraint on the volume dimension of production, geopolitical shock is a

fast-moving, unplanned constraint on the availability dimension: it does not change the economic attractiveness of a reserve or a piece of infrastructure, but it can remove that infrastructure's capacity to produce or export entirely, for a period bounded by repair and reconstruction rather than by demand or policy. In Real Options terms, this class of event functions as an exogenous shift in the strike price and timing of option exercise rather than as a change in the underlying asset's fundamental value: a facility taken offline by an attack has not been repriced by the market the way a facility exposed to demand decline has, and the option to resume production is one the operator holds involuntarily rather than one exercised by choice.

The two mechanisms are conceptually distinct from the multi-decade demand-transition risk this thesis otherwise models, and from each other. Quota coordination is a recurring, negotiated feature of GCC producer behavior with a clear precedent and a documented institutional history; geopolitical shock is acute, unplanned, and, for any single facility, rare. Sections 4.4 and 5.6 apply both distinctions to specific empirical cases: OPEC+ quota mechanics to the cost-curve argument developed in Chapter 4, and a 2026 geopolitical disruption to QatarEnergy's Ras Laffan facility to the case study developed in Chapter 5.

2.9 Synthesis

These eight literatures form the analytical scaffolding for what follows. The financial stranded-asset literature (Section 2.1) supplies the valuation vocabulary and methodological precedent used in Chapter 4. The Green Paradox and Real Options Theory (Section 2.2), synthesized here as the Dual-Mechanism Rentier Adaptation Model, together explain the capacity-acceleration and reinvestment behavior otherwise read in Chapter 4 through a cost-curve lens alone, a synthesis revisited directly in Section 6.1. Resource curse and rentier state theory (Section 2.3) establish why stranded-asset risk must be analyzed at the sovereign level as

well as the corporate one, carried forward into Chapter 6. Strategic resilience and adaptation theory (Section 2.4) sets up, and is ultimately subordinated to, the Real Options framework adopted in Chapter 3. GCC-specific energy transition literature (Section 2.5) provides the empirical scale of regional decarbonization investment against which Chapter 5's case studies are read. The financial-regulatory literature on climate risk disclosure (Section 2.6) situates the data-opacity limitation in its practical context and points toward how that limitation may eventually resolve. The identified research gap (Section 2.7) marks out the specific contribution: a stranded-asset analysis of GCC NOCs on their own analytical terms, not an extension of IOC-oriented, Global-South-oriented, or renewables-deployment-oriented frameworks built for different purposes. The exogenous volatility framework (Section 2.8) supplies the conceptual apparatus, administered volume constraints and geopolitical shock as distinct from demand-transition risk, applied empirically in Sections 4.4 and 5.6.

Chapter 3: Theoretical Framework and Methodology

3.1 Theoretical Framework: Real Options Theory

This thesis adopts Real Options Theory as its primary analytical lens. Originating in Myers's (1977) observation that corporate investment opportunities can be understood as analogous to financial call options, and formalized thoroughly by Dixit and Pindyck (1994) in *Investment Under Uncertainty*, Real Options Theory treats an irreversible investment decision made under uncertainty as an option: the firm holds the right, but not the obligation, to invest, expand, delay, or abandon a project as new information arrives, and this flexibility itself has quantifiable value distinct from a static net-present-value calculation.

The framework has direct precedent in petroleum-sector investment analysis specifically, which strengthens its fit for this thesis beyond a generic strategy-theory import. Abdul-Salam (2022), writing in *The Energy Journal*, applies real options analysis to the specific question of optimal timing for oil field decommissioning under joint oil-price and carbon-tax uncertainty, finding that carbon taxation meaningfully accelerates the optimal decommissioning window. This is directly relevant to how this thesis frames GCC capacity-expansion decisions as option-preserving bets against an uncertain carbon-policy trajectory. Breitenstein et al. (2022), examining stranded-asset risk in the German coal phase-out, provide a second petroleum- and fossil-fuel-adjacent precedent for applying option-value and political-uncertainty framing to stranding risk specifically, rather than to generic investment timing.

Applied to this thesis, Real Options Theory reframes GCC NOC investment in CCUS, crude-to-chemicals conversion, and blue hydrogen infrastructure not as a contradiction of continued hydrocarbon expansion, but as a portfolio of options being purchased against the possibility that hydrocarbon demand declines faster than the Current Policies trajectory. Each

investment preserves a future pathway, whether a decarbonized barrel, a non-combustion end use, or a hydrogen export market, without requiring the firm to abandon the core business today.

3.2 Framework Selection: Real Options Theory Against Its Alternatives

This framing was evaluated formally against the two alternatives introduced in Section 2.4 before being adopted. Barney's (1991) Resource-Based View was considered first. It explains why GCC NOCs can pursue diversification at all: their low-cost reserve base is a valuable, rare, and difficult-to-imitate resource in Barney's VRIN sense, generating the cash-flow slack that funds diversification. But it offers no analytical machinery for determining when a specific hedge is worth making or how large it should be, which is precisely what RQ2 and RQ3 require. Teece, Pisano, and Shuen's (1997) Dynamic Capabilities framework was considered second. It better captures the organizational-adaptation dimension of GCC NOC behavior, namely the observed capacity to reconfigure toward CCUS, CTC, and hydrogen infrastructure in response to a changing external environment, but like the Resource-Based View it is qualitative by construction and does not generate the quantitative, scenario-comparable exposure estimates this thesis needs for Chapter 4.

Real Options Theory was ultimately preferred because it is the only one of the three frameworks that supplies both an organizational logic, in which flexibility has value under uncertainty, and a formal valuation mechanism: option-pricing-adjacent techniques, here operationalized through the scenario-based discounted cash flow approach described in Section 3.4, that can be applied consistently across both the quantitative and qualitative phases of this thesis's mixed-methods design.

The quantitative model developed in Section 3.4 operationalizes Real Options Theory through a scenario-based discounted cash flow approach rather than a formal option-pricing

model, such as the binomial lattice or Black-Scholes-derived methods more commonly associated with real options valuation in the corporate finance literature. Formal option-pricing models require inputs, including a defined volatility parameter for the underlying asset and a specified exercise price and expiration structure, that are estimable for a financial option but not estimable for a sovereign-owned reserve base with no market-traded price, no defined expiration date, and no disclosed volatility of underlying cash flows, an opacity constraint examined as a structural feature of state ownership in Section 3.5. The three-scenario, two-bookend design adopted in Section 3.4 substitutes for this missing data: each scenario functions analogously to a state of the world in a decision tree, and the Model A/Model B spread functions analogously to the value of flexibility a formal option-pricing model would price directly, without requiring the volatility and exercise-price inputs GCC NOC opacity withholds. A successor study with access to the more granular, market-disclosed data flagged as increasingly likely in Section 6.4 could extend this analysis to a formal option-pricing framework; this thesis calibrates its own contribution to the data actually available.

3.3 Methodological Approach

This thesis adopts a pragmatist, mixed-methods design combining a quantitative scenario-modeling phase with a qualitative comparative case study, on the grounds that RQ1 (financial exposure quantification) and RQ2/RQ3 (strategic and capital-allocation behavior) require different evidentiary approaches that are more informative combined than either would be alone. This design corresponds directly to the two-tiered unit of analysis defined in Section 1.4: RQ1's quantitative valuation scope (Aramco, ADNOC, and the ExxonMobil benchmark) and RQ2/RQ3's broader qualitative strategic and capital-allocation scope (extending to QatarEnergy and international vehicles such as XRG) are not two applications of one case list,

but two deliberately different samples, each matched to the evidentiary requirements of the research question it serves.

Qualitative phase. A comparative case study of Saudi Aramco, ADNOC, and QatarEnergy is conducted using secondary and publicly available sources only: annual reports, sustainability disclosures, investor presentations, and verified industry and trade press reporting on capacity expansion and diversification investment. No primary interview data is used. This is a deliberate scope decision rather than an oversight. GCC NOCs are, as a matter of established industry commentary, unusually opaque regarding internal decision-making, and a primary-interview approach was judged likely to yield low response rates and selection bias toward already-public positions, making a systematic secondary-source case study a more reliable and reproducible method for a thesis at this level. Case study findings are reported in Chapter 5.

3.4 The Scenario-Based Financial Exposure Model

Consistent with the quantitative valuation scope defined in Section 1.4, the quantitative phase estimates financial exposure using a simplified discounted cash flow (DCF) approach applied to Saudi Aramco and ADNOC, the two companies in the sample for which sufficiently comparable public data exist to support a scenario comparison, and to ExxonMobil, included specifically as an IOC benchmark so that RQ1's comparative question has an actual comparator figure rather than only a qualitative contrast. As established in Section 1.4, QatarEnergy is evaluated qualitatively rather than within the per-barrel DCF model, given the structural incommensurability of LNG pricing frameworks, through the capacity expansion and market-position case study in Chapter 5.

For each company, annual upstream margin is estimated as reported or estimated daily production, annualized, multiplied by the difference between a scenario oil price and an

estimated per-barrel production cost. This margin is then converted to a present value using an ordinary annuity formula over a 25-year analysis horizon (2026 to 2050, matching the IEA's (2025) modeling horizon) at an 8% discount rate, a conventional discount rate in extractive-industry corporate valuation and consistent with rates used in comparable academic reserve-valuation work (Atanasova & Schwartz, 2020). All figures are modeled in constant, present-value dollars; no separate inflation escalation is applied to prices or costs across the horizon, consistent with standard real-terms scenario practice, and this simplification is treated as a stated limitation below rather than a hidden assumption. Because the cash flows discounted are already stated in constant dollars, the 8% rate is applied throughout as a real hurdle rate rather than a nominal weighted average cost of capital, and it is set toward the upper end of the range used in comparable long-horizon extractive-asset valuation specifically to guard against overstating the reserve margin NPVs reported in Chapter 4. Three price scenarios are used, corresponding to the IEA's (2025) Current Policies, Stated Policies, and Net Zero Emissions by 2050 scenarios, at approximately \$96, \$80, and \$65 per barrel respectively. These figures are derived from a synthesis of IEA-implied pricing, the U.S. Energy Information Administration's Annual Energy Outlook 2026 reference-case Brent projections, and the International Energy Forum's cross-agency Outlooks Comparison Report (EIA, 2026; International Energy Forum, 2026).

Production and cost inputs are necessarily asymmetric across the three companies, and this asymmetry is itself methodologically significant. Aramco's production (approximately 10 million barrels per day) and fully loaded upstream production cost (approximately \$9 to \$10 per barrel) are drawn from company-adjacent public reporting (Arab News, 2019). ADNOC does not disclose a comparably granular production-cost figure, so this thesis models a cost band of \$15 to \$27 per barrel rather than a single point estimate, with the upper bound anchored to the regional

Middle East onshore breakeven proxy and the lower bound an illustrative floor, applied to an estimated average production rate of 4.5 million barrels per day reflecting its trajectory toward the 5 million barrel-per-day 2027 target (OilPrice.com, 2026). ExxonMobil's inputs are its approximate 3 million barrel-per-day crude and liquids production, consistent with the 3.329 million barrels per day the company reported for full-year 2025 (ExxonMobil, 2026), and its company-stated 2030 breakeven cost target of \$30 per barrel, drawn from its investor disclosures; this is a forward-looking target rather than a currently disclosed actual cost, a distinction preserved in the presentation of results in Chapter 4. The need for a cost band for ADNOC and a target rather than an actual figure for ExxonMobil is itself direct empirical evidence, generated by the exercise of building the model, of the data-opacity limitation stated in Section 3.5 and in Chapter 1: it is only for state-owned Aramco, paradoxically, that a precise company-disclosed cost figure is available at all.

A second design choice addresses a specific analytical gap: a price-only scenario model, however carefully constructed, cannot by itself substantiate the volume-based cost-curve argument developed in Section 4.1, since holding production flat across all three scenarios silently assumes the very cost-curve protection the thesis sets out to demonstrate. To avoid this circularity, the model is run in two versions. Model A holds annual production constant across all three scenarios, an upper bookend representing full cost-curve protection, in which a producer's volume is entirely insulated from global demand change because higher-cost supply exits the market first. Model B instead scales each company's annual production by the ratio of 2050 to present-day global oil demand under the same scenario, using IEA and EIA figures (Current Policies: demand rises from approximately 103 to 113 million barrels per day; Stated Policies: demand plateaus near a 102 million barrel-per-day peak reached around 2030; Net Zero

Emissions: demand falls to 24 million barrels per day by 2050, a decline the IEA describes as approximately 75%; IEA, 2025b, 2026). Model B is a lower bookend representing zero relative cost-curve advantage, in which a company's volume simply tracks the global market. Neither bookend is proposed as the most likely outcome; the gap between them in a given scenario is instead read, in Section 4.4, as an approximate monetary expression of the cost-curve advantage documented qualitatively in Section 4.1. Full results, and the full assumption set underlying them, are presented in Chapter 4 and Appendix A, and are reproduced with live formulas in the companion spreadsheet described in Appendix A.

3.5 Validity, Reliability, and Stated Limitations

Construct validity for the quantitative phase rests on the reasonableness of the IEA scenario framework as a proxy for underlying demand uncertainty. This is a standard and widely used framework in the stranded-asset literature (Atanasova & Schwartz, 2020; Daumas, 2024) and is treated as an appropriate, if imperfect, basis for scenario construction. Reliability of the qualitative case study rests on triangulating each factual claim about company strategy across at least two independent sources, typically company disclosure plus independent trade press or analyst commentary, wherever possible.

GCC NOCs do not disclose internal reserve valuation methodology, asset-level write-down assumptions, or detailed cost data at the granularity available for SEC-registered IOCs. This opacity is not incidental to state ownership; it is a structural feature of state-owned enterprise political economy, consistent with Section 2.6's account of why NOCs face no equivalent investor-driven disclosure pressure absent public capital markets access. Every quantitative exposure figure produced in Chapter 4 is accordingly built on public, aggregated, and in places third-party-modeled proxy inputs rather than an audited or company-disclosed

figure, and the third-party institutional baselines this thesis relies on, principally IEA and EIA scenario and price data, function as the external reference capital markets themselves use in the absence of NOC-disclosed figures, not as a second-best substitute for them. Second, the Model A / Model B bookend approach described in Section 3.4 addresses the volume-differentiation gap directly but does not resolve it precisely: the true production path for any of the three companies under a given scenario is not known from public information and likely sits between the two bookends rather than at either one. Third, the ExxonMobil benchmark in Chapter 4 compares production-cost economics only; it is not a like-for-like reserve comparison, since Aramco's and ADNOC's disclosed reserves are crude oil only, while ExxonMobil's disclosed reserves are stated on an oil-equivalent basis that includes natural gas. Fourth, no inflation escalation is applied across the 25-year horizon, so all results are best read as constant-dollar, order-of-magnitude estimates rather than nominal cash-flow forecasts. These features shape the interpretation of Chapter 4's findings throughout: the analysis establishes direction and order of magnitude of relative exposure, using the same external baselines capital markets themselves rely on, rather than replicating a precision NOC disclosure practice does not make available to any researcher.

3.6 Researcher Positionality

A final methodological note addresses the researcher's position relative to this thesis's subject matter, following Berger's (2015) framework for reflexivity in qualitative research. Berger identifies three researcher positions: sharing the experience of study participants, moving from outsider to insider status during the study, and having no personal familiarity with the subject at all. This thesis's author approaches the GCC oil and gas sector from the third position, as an external analyst without institutional affiliation to Aramco, ADNOC, QatarEnergy, or the

GCC states themselves. Berger's (2015) framework treats this position as carrying a specific, named trade-off rather than a generic limitation: an external analyst is less exposed to the access-dependent bias that can affect insider research on politically sensitive state-owned enterprises, since this thesis's argument does not depend on continued access or goodwill from any of the three companies studied, but is correspondingly more dependent on secondary, publicly disclosed sources, which is the same data-opacity constraint already identified as this thesis's central limitation above. The reflexive implication is that this thesis's outsider position is a partial explanation for, not merely a background fact alongside, its heavy reliance on triangulated secondary sources rather than primary interview data.

Chapter 4: Assessing the Stranded Asset Risk in the GCC

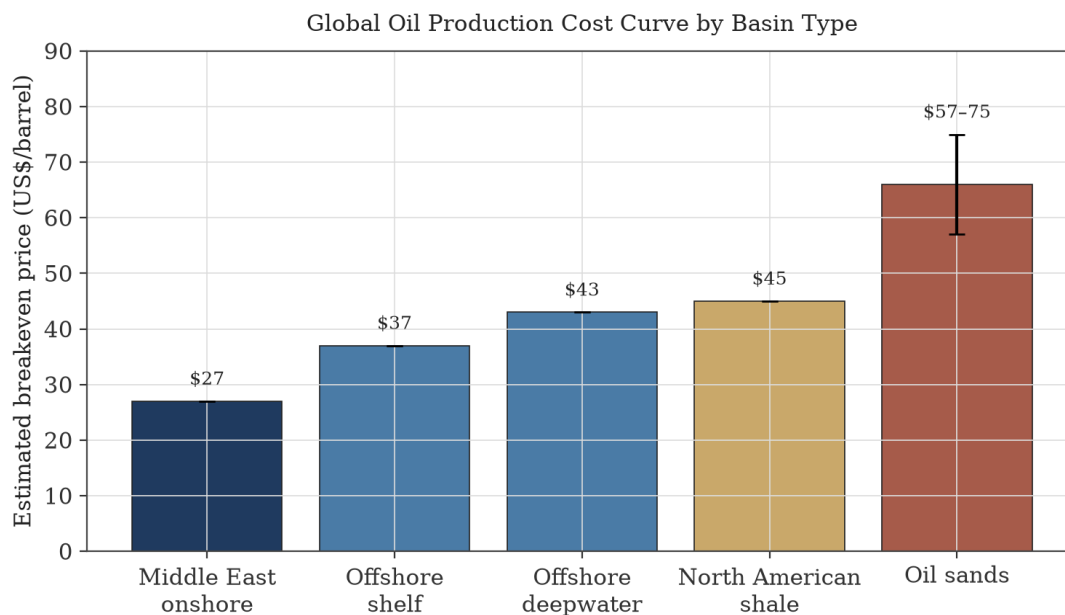
4.1 The Cost-Curve Advantage: The “Last Barrel Standing” Position

Global oil production cost curves consistently place Gulf onshore production at the lowest-cost end of the global supply stack, with breakeven estimates for new Middle East onshore production around \$27 per barrel, materially below offshore shelf (\$37), offshore deepwater (\$43), North American shale (~\$45), and oil sands (\$57 to \$75), illustrated in Figure 4.1. Saudi Aramco specifically has reported upstream production costs as low as \$2.8 per barrel, and more recent 2025 reporting places the figure at approximately \$9 to \$10 per barrel on a fully loaded basis. In either case, this is a cost position that remains profitable at Brent prices that would force the majority of global producers into loss-making operation (Arab News, 2019). Fattouh's (2021) analysis of Saudi oil policy for the Oxford Institute for Energy Studies reinforces this reading at the market-strategy level, arguing that GCC producers cannot sustainably pursue a higher-volume, lower-price strategy that prices oil below full cost of production, but that their comparatively low production cost gives them meaningfully more room to defend market share through a period of price pressure than higher-cost competitors, including US shale producers, whose entry has already complicated the effectiveness of both OPEC's and Saudi Arabia's traditional market-management tools.

This cost-curve ordering should not be read as mechanically deterministic, however. Fellows's (2022) analysis of Canadian oil sands production for the C.D. Howe Institute offers a methodological caution directly relevant to Figure 4.1's ranking: oil sands, classified in Figure 4.1 among the highest-cost basins on a full-cycle breakeven basis, nonetheless exhibit low marginal operating costs, in the range of C\$5 to C\$35 per barrel once initial capital is sunk, meaning producers continue operating well below the price level a full-cycle cost curve would

suggest is required to sustain them. The same logic, that near-term exit ordering tracks marginal operating cost more closely than full-cycle breakeven cost, could in principle apply to any basin with already-sunk capital, including GCC production itself, and it means the “last barrel standing” argument developed here is more reliable as a guide to where new capital is deployed than as a guide to which existing barrels stop producing first during a demand downturn. This thesis's cost-curve argument is accordingly read throughout as a statement about the economics of new and continued investment, the frame in which Chapter 4's exposure model is built, rather than as a claim that GCC production is necessarily the last to physically shut in during a price collapse.

Figure 4.1



Note. Illustrative breakeven ranges for new production by basin type, US\$ per barrel.

Source: Industry cost-curve analysis (compiled from EIA-adjacent and Hagen Energy Consulting summaries; see Chapter 4).

This cost position is the empirical basis of the “last barrel standing” thesis: in a global demand-decline scenario, the market-clearing mechanism is not a uniform proportional cutback across all producers but a sequential exit of the highest-cost supply first, as declining prices push

marginal producers below their breakeven point while low-cost Gulf production remains profitable. Under this logic, GCC reserves are structurally the least likely to be stranded first, a materially different position than the higher-cost Western IOC reserves that dominate the existing stranded-asset literature (Daumas, 2024; Atanasova & Schwartz, 2020).

The advantage is relative, not absolute: it changes the order in which global reserves become uneconomic under demand decline, not whether GCC reserves are exposed to decline at all. Under the IEA (2025) Net Zero Emissions Scenario specifically, in which no new long-lead-time fields are required globally and some existing fields close early, even low-cost reserves face a shrinking addressable market, meaning the cost-curve advantage delays but does not eliminate exposure.

4.2 Policy and Trade Risks: A Correction to the Conventional Framing

A common framing in industry and popular commentary treats the European Union's Carbon Border Adjustment Mechanism (CBAM) as an active, present-day mechanism artificially penalizing GCC oil and gas exports. This framing requires correction. As of 2026, CBAM's definitive phase, which began January 1, 2026, with the first quarterly certificate price published April 7, 2026 at €75.36 per tonne of CO₂e, covers cement, iron and steel, aluminium, fertilizers, electricity, and hydrogen (European Commission, 2026). Crude oil, most refined petroleum products, and most organic chemicals are not currently within CBAM's scope; expansion of coverage to organic chemicals and polymers has been postponed, with broader petrochemical coverage not anticipated before approximately 2030.

The mechanics of this transition are worth stating precisely, since they explain why the fertilizer exposure identified below is financial rather than merely administrative. From October 2023 through December 2025, CBAM operated in a reporting-only transitional phase: importers

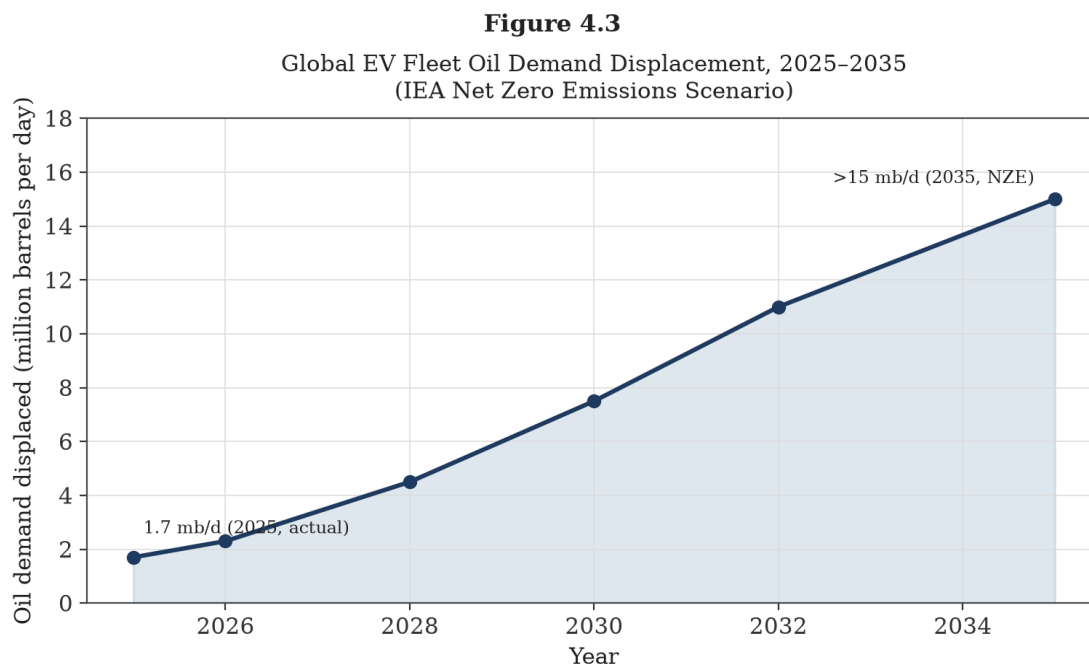
of covered goods, including Saudi and Qatari ammonia and urea, were required to report the embedded emissions of each shipment on a quarterly basis but faced no certificate-purchase obligation and no direct cost. That changed with the definitive phase's start on January 1, 2026: EU importers of covered goods must now surrender CBAM certificates priced to track the EU Emissions Trading System carbon price, noted above at €75.36 per tonne of CO₂e for the first 2026 quarterly reference price, converting what was a compliance exercise into a direct cost passed through the ammonia and urea supply chain. For GCC exporters, this means the fertilizer-sector exposure identified in this section, unlike the anticipated future exposure in petrochemicals, is no longer prospective as of the date of this analysis; it is a live cost already embedded in 2026 trade flows.

This correction changes, rather than eliminates, the relevant policy-risk analysis. Two implications follow. First, GCC states are not currently exposed to CBAM on their crude oil exports, meaning near-term trade-policy risk to core upstream revenue is lower than the conventional framing suggests. Second, GCC states are currently exposed on a narrower but real front: fertilizer products, namely ammonia and urea, both significant Saudi and Qatari exports, are within CBAM's current scope, making this a live, present-day trade-policy exposure rather than a hypothetical future one. The appropriate framing for this thesis is therefore twofold: current, real exposure concentrated in fertilizer and ammonia trade, and anticipated, forward-looking exposure in petrochemicals and potentially crude derivatives as CBAM's scope expands toward 2030. This reframing is itself a finding of this thesis's literature and policy verification process, and stands as a correction to less rigorously sourced popular commentary on the subject.

4.3 Technological Risk: Electrification and Demand-Side Displacement

The pace of electric vehicle adoption represents a demand-side risk vector distinct from cost-curve or trade-policy risk. The IEA's Global EV Outlook 2026 reports that global electric car sales reached over 20 million units in 2025, a 25% share of the overall car market, with 2026 sales forecast to approach 30% of total vehicle sales worldwide (IEA, 2026). The global EV fleet displaced approximately 1.7 million barrels of oil demand per day in 2025, a figure the IEA projects will exceed 15 million barrels per day of avoided demand by 2035 under the Net Zero Emissions Scenario (IEA, 2026), illustrated in Figure 4.3. China alone is projected to displace 2.7 million barrels per day of oil demand annually by 2030 through EV deployment (IEA, 2026).

For GCC producers, this risk vector operates primarily on the demand side rather than the supply-cost side addressed in Section 4.1: even a cost-advantaged producer faces revenue erosion if the addressable market for its product shrinks, independent of its position on the cost curve. This is the demand-side counterpart to the CBAM-driven trade-policy risk discussed above, and together the two vectors motivate the strategic-resilience responses examined in Chapter 5, particularly crude-to-chemicals conversion, which is explicitly designed to redirect a barrel of crude away from transport-fuel combustion (the end use most exposed to EV displacement) toward petrochemical feedstock demand (an end use with a materially different, and currently less EV-comparable, displacement risk profile).



Note. 2025 figure is IEA-reported actual; 2035 figure is IEA NZE-scenario projection; interior years are linear interpolations for illustration, not independently sourced annual IEA figures.
Source: IEA, Global EV Outlook 2026.

4.4 OPEC+ Market Management as a Complicating Factor

The cost-curve argument developed in Section 4.1 treats production volume as if it were set purely by marginal-cost competition: low-cost barrels stay in the market, high-cost barrels exit first. In practice, Saudi Arabia's and, to a lesser extent, the UAE's production decisions are not made unilaterally on cost grounds alone; they are coordinated through OPEC+, and Saudi Arabia has repeatedly cut production below what its cost position alone would justify to defend prices, most visibly through its role as the group's swing producer. In the terms developed in Section 2.8, this coordination functions as an administered volume constraint: a collectively negotiated ceiling that can override marginal-cost competition in either direction, rather than a market outcome the cost curve alone determines. Saudi Arabia holds on the order of 3 million barrels per day of spare production capacity, some 60% of spare capacity worldwide as of Finley's (2024) analysis, a share that moves with the prevailing phase of the OPEC+ cut cycle

and the specific baseline against which spare capacity is measured, but that has consistently left Saudi Arabia with an unused margin far greater than any other single producer's, functioning as a strategic instrument for market management rather than idle capacity awaiting a cost-driven opportunity to produce (Finley, 2024).

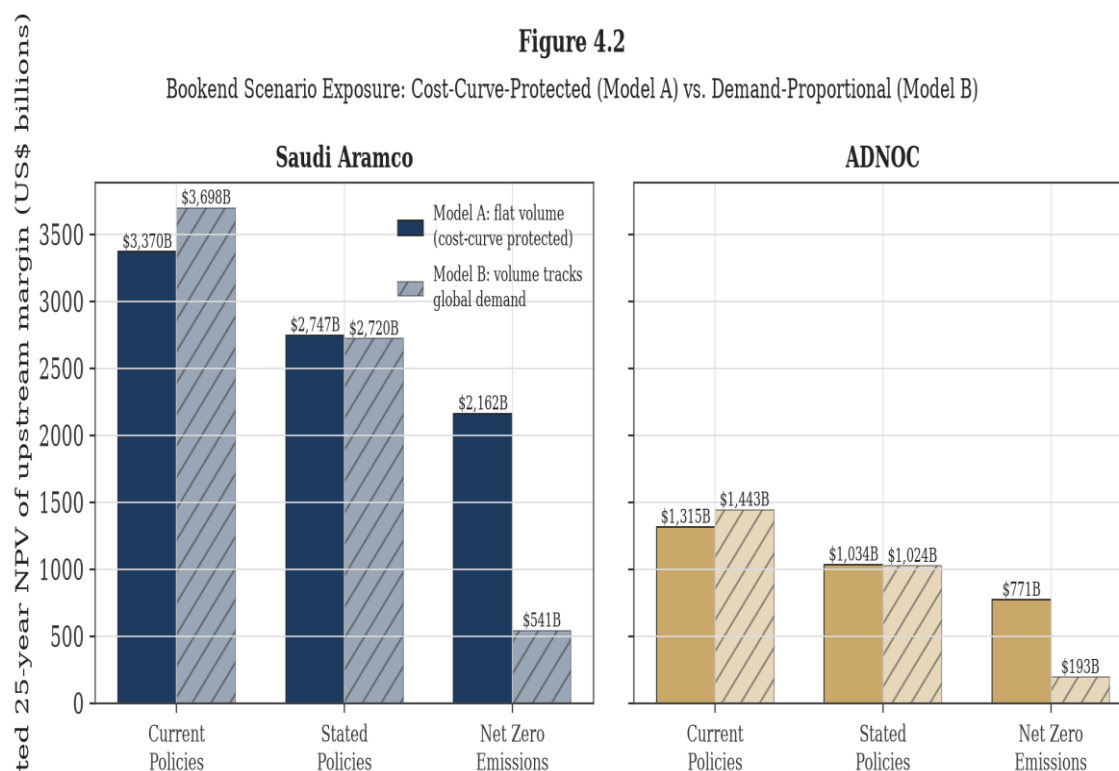
A new OPEC+ quota mechanism, set to take effect from 2027, reinforces rather than undermines the capacity-expansion trend documented in Chapter 5: it is designed to reward members with higher production capacity with higher baseline quotas, meaning ADNOC's and Saudi Arabia's ongoing capacity investments (Section 5.1) also function as a bid for a larger share of future OPEC+ output allocation, not only as a hedge against demand decline. This complicates the pure cost-curve reading of Section 4.1 in one specific way relevant to RQ1: GCC producers' actual near-term production path is a function of price-defense coordination as well as cost position, meaning the “last barrel standing” argument describes GCC producers' position in a fully competitive, demand-constrained market more accurately than it describes their production behavior in the price-managed market that actually exists today. The Model A and Model B bookends introduced in Section 3.4 and applied in Section 4.5 should be read with this caveat: Model A's assumption of full cost-curve protection implicitly assumes production is unconstrained by quota-driven price management, an assumption OPEC+'s actual operating history does not fully support. This is the empirical instance of the administered-volume-constraint mechanism introduced in Section 2.8: GCC producers' near-term output path reflects negotiated quota coordination as much as marginal cost, and Chapter 4's cost-curve model is accordingly a baseline the actual market only partially follows, not a description of realized production.

4.5 Quantifying Exposure: Scenario Model Results

Applying the model described in Section 3.4, estimated 25-year present value of upstream margin for Saudi Aramco under Model A (flat volume, full cost-curve protection) ranges from approximately \$2,162 billion under the Net Zero Emissions scenario to \$3,370 billion under the Current Policies scenario, a difference of roughly \$1.2 trillion, or 36%, between the most and least favorable demand pathways (see Figure 4.2). For ADNOC, using the midpoint of the \$15-to-\$27 cost band described in Section 3.4, the corresponding Model A range runs from approximately \$771 billion (Net Zero Emissions) to \$1,315 billion (Current Policies); the cost band alone, independent of the price scenario, produces roughly a \$210 billion span in the Current Policies estimate (from \$1,210 billion at the high-cost end to \$1,420 billion at the low-cost end), which is a direct, quantified expression of the structural data opacity discussed in Section 3.5: a fifth of ADNOC's estimated exposure range under a single scenario is attributable to the cost band standing in for a figure ADNOC, as a matter of ownership structure rather than researcher access, does not publicly disclose.

Model B (volume tracking global demand, zero relative cost-curve advantage) produces a materially different and more informative picture. Under Net Zero Emissions, Aramco's Model B estimate falls to approximately \$541 billion, a quarter of the Model A figure for the same scenario; ADNOC's falls to approximately \$193 billion, similarly around a quarter of its Model A figure. This roughly fourfold gap between the two bookends is this thesis's quantified answer to the volume-differentiation question raised in Section 3.4: it approximates the value of the cost-curve advantage documented qualitatively in Section 4.1, under the Net Zero Emissions scenario specifically, where the difference between being demand-constrained and being cost-curve-protected is largest. Under Current Policies, by contrast, Model B slightly exceeds Model A for both companies (for example, Aramco's Model B estimate of \$3,698 billion versus its Model A

estimate of \$3,370 billion), because global demand is itself growing in that scenario; tracking a growing market outperforms staying flat. The direction of the Model A/B gap therefore flips with the direction of global demand, which is itself a finding: the cost-curve advantage has no value when the market is growing, and its largest value precisely when the market is shrinking fastest, which is the scenario in which GCC producers most need it.



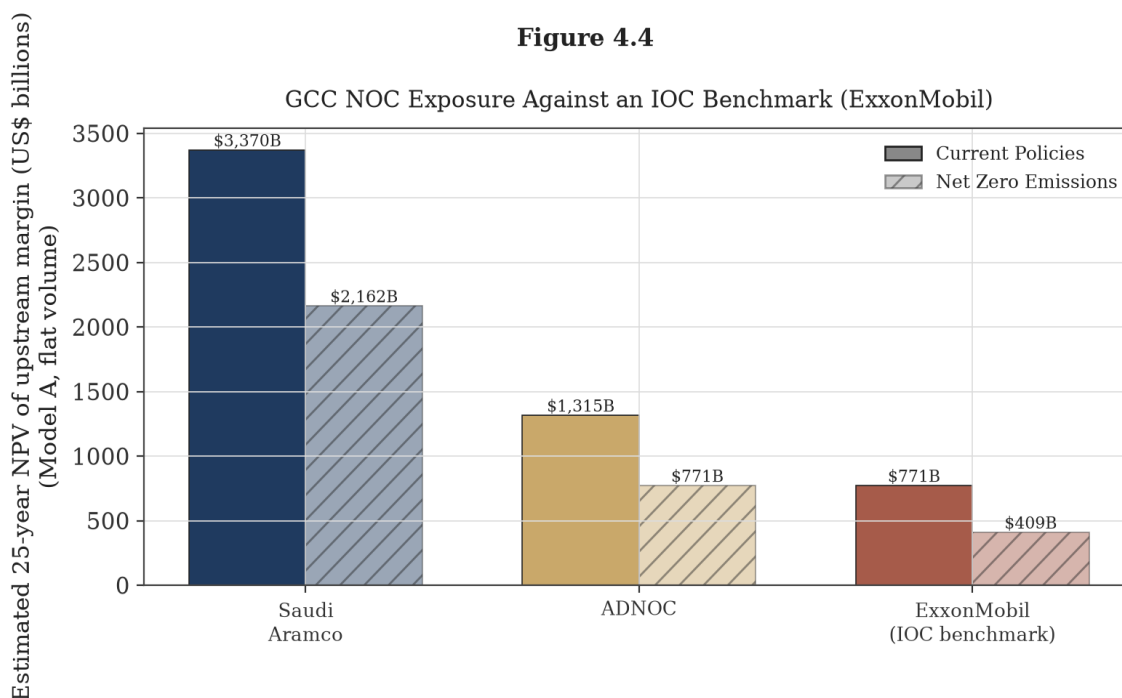
Note. Model A holds volume flat across all scenarios, an upper bookend representing full cost-curve protection. Model B scales volume with global oil demand (IEA/EIA 2025-2026: Current Policies 103–113 mb/d; Stated Policies plateaus near a 102 mb/d peak; Net Zero Emissions falls to 24 mb/d, an IEA-stated ~75% decline), a lower bookend assuming zero relative cost-curve advantage. The gap between A and B in a given scenario approximates the value of the cost-curve advantage documented in Section 4.1. Both remain illustrative, not audited, estimates.

Two further findings follow and speak directly to RQ1. First, in absolute terms, Aramco's Model A exposure swing (~\$1.2 trillion) dwarfs ADNOC's (~\$544 billion), simply reflecting Aramco's larger reserve base and production volume, an expected result that mainly validates the model's internal consistency rather than offering new insight. Second, Section 4.4's OPEC+

caveat applies most directly to Model A: to the extent that GCC production is managed through quota coordination rather than pure cost competition, actual outcomes for Aramco and ADNOC likely sit closer to Model A than Model B specifically because of that coordination, and not solely because of the cost-curve advantage the model was designed to isolate. Disentangling how much of Model A's relative optimism reflects cost-curve protection versus OPEC+ price management is not possible from public information and is flagged here as a limitation rather than resolved.

4.6 GCC NOC Exposure Against an IOC Benchmark

ExxonMobil enters the analysis here not as an additional case but as the empirical verification tier of the quantitative valuation scope defined in Section 1.4. RQ1 asks specifically how GCC NOC exposure compares to that of higher-cost Western IOCs, and Sections 4.1 through 4.5 have so far supported the “last barrel standing” cost-curve differential only qualitatively. Applying the same Model A methodology to ExxonMobil, using its approximately 3 million barrel-per-day crude and liquids production and its company-stated 2030 breakeven cost target of \$30 per barrel (Section 3.4), tests that differential directly against a real, disclosed IOC cost position rather than only against the literature's general characterization of IOCs as higher-cost, producing an estimated 25-year exposure of approximately \$771 billion under Current Policies, falling to approximately \$409 billion under Net Zero Emissions, illustrated in Figure 4.4.



Note. ExxonMobil inputs: ~3 mb/d crude and liquids production; \$30/bbl company-stated 2030 breakeven cost target (not a current disclosed actual). Reserves basis differs (Aramco/ADNOC crude oil only; ExxonMobil's disclosed 19.3 billion barrels is oil-equivalent, including gas), so this compares production-cost economics, not like-for-like reserve valuation. Illustrative estimate, not an audited or company-disclosed figure.

Three results follow. First, ExxonMobil's absolute exposure sits below both Aramco's and, under Current Policies, ADNOC's, which mechanically reflects ExxonMobil's smaller modeled production volume rather than a claim about total company value; ExxonMobil is a much larger and more diversified enterprise than this single upstream-margin metric captures, and the comparison is intentionally narrow, matching only the production-cost economics the three companies' Model A inputs share. Second, and more analytically relevant, ExxonMobil's proportional decline from Current Policies to Net Zero Emissions is approximately 47%, comparable to or larger than Aramco's 36% and closer to ADNOC's cost-band-dependent 34% to 45% range, despite ExxonMobil's cost position (\$30/bbl target) sitting between Aramco's and ADNOC's on the cost curve documented in Figure 4.1. This is consistent with, and lends some independent support to, this thesis's central cost-curve argument: exposure sensitivity to the demand pathway tracks cost position more closely than it tracks company nationality or

ownership structure. Third, the gap between ExxonMobil's \$30/bbl breakeven target and Aramco's disclosed \$9-to-\$10 fully loaded cost is real but, set against the \$37-to-\$75 range spanned by offshore shelf, deepwater, and shale production in Figure 4.1, comparatively narrow; a well-run diversified major at its own best-case cost target is not dramatically more exposed than the ADNOC cost-band proxy used in this thesis, which suggests the sharpest cost-curve divide in Chapter 4's analysis runs less between “GCC” and “IOC” as ownership categories and more between low-cost conventional production of any ownership structure and high-cost supply such as oil sands and marginal shale.

4.7 Cross-Check Against Independent Estimates

As a partial validation exercise, this thesis compares its scenario-model outputs against Carbon Tracker's independent, project-level stranded-asset analysis. Coffin and Grant (2020) find that approximately \$60 billion of capital expenditure associated with the fifteen largest oil and gas projects sanctioned globally in 2019 is not economically competitive under IEA climate-aligned demand scenarios. This figure is not directly comparable to this thesis's reserve-margin exposure estimates: Carbon Tracker's analysis is project-level and capital-expenditure-denominated, whereas this thesis's model is reserve-level and margin-denominated. Still, the two approaches are directionally consistent, in that both identify a materially large absolute value at risk under climate-aligned scenarios, and neither approach identifies GCC-specific projects among the highest-risk category, consistent with this chapter's cost-curve-based finding that GCC reserves and projects are comparatively insulated relative to the higher-cost projects that dominate Carbon Tracker's at-risk project list. This cross-check should be read as weak corroboration of directional plausibility, not as independent verification of this thesis's specific

dollar figures, which remain, as stated throughout, illustrative estimates rather than audited valuations.

4.8 Sensitivity of Results to Discount Rate Assumptions

The 8% discount rate adopted in Section 3.4 is a conventional but not uncontestable choice, and the exposure figures reported above are meaningfully sensitive to it. Applying the same Model A methodology to Saudi Aramco's Current Policies and Net Zero Emissions scenarios at 6% and 10% discount rates, holding all other inputs constant, produces the following range: under Current Policies, estimated 25-year exposure rises to approximately \$4,036 billion at a 6% discount rate and falls to approximately \$2,866 billion at 10%, against the \$3,370 billion base case reported in Section 4.5; under Net Zero Emissions, the corresponding range runs from approximately \$2,590 billion at 6% to approximately \$1,839 billion at 10%, against a \$2,162 billion base case. A two-percentage-point change in either direction moves the estimate by roughly 15% to 20%, a sensitivity of broadly similar proportional magnitude to the scenario-to-scenario variation the model is principally designed to capture.

This sensitivity does not undermine the scenario comparison at the center of Chapter 4's argument, since the discount rate is held constant across all three price scenarios and both companies, meaning the proportional gap between Current Policies and Net Zero Emissions exposure, the comparison this thesis actually relies on, is materially unaffected by which single discount rate is chosen. It does mean that the absolute dollar figures reported throughout Chapter 4 and Appendix A should be read as order-of-magnitude estimates conditional on a conventional, but ultimately judgment-based, discount rate assumption, consistent with the limitation already stated in Section 3.5, rather than as figures precise to the reported significant digits. Readers who prefer a different discount rate can recompute the full model directly in the companion

spreadsheet described in Appendix A.3, which exposes the discount rate as a single adjustable input.

Chapter 5: Strategic Resilience and Adaptation Strategies

5.1 Mapping Risk to Response

This chapter maps the risk vectors identified in Chapter 4 onto the specific strategic-resilience mechanisms GCC NOCs are deploying in response, drawing on the Real Options Theory framing established in Chapter 3: each response is treated as an option purchased against a specific risk, not as a wholesale strategic pivot away from hydrocarbons. Table 5.1 summarizes the mapping; Sections 5.4 to 5.6 then examine each company individually in greater depth.

Table 5.1 *Mapping of Transition Risk Vectors to GCC NOC Strategic Resilience Responses*

Risk Vector	Strategic Resilience Response	Verified Examples
Emissions-intensity penalties (current: fertilizer/ammonia CBAM exposure; anticipated: broader CBAM expansion toward 2030)	Decarbonizing the barrel via CCUS	ADNOC's Al Reyadah facility, the first commercial-scale CCUS project in the Middle East, capturing up to 800,000 tonnes of CO ₂ annually for enhanced oil recovery, and its Habshan CCUS project (final investment decision taken; 1.5 million tonnes per annum capacity, targeted 2026 completion); Saudi Aramco's Jubail CCUS hub with SLB and Linde, targeting 9 million tonnes per annum by 2027, of which Aramco is responsible for 6 million tonnes
Transport-fuel demand erosion from EV adoption	Pivoting to chemicals / non-combustible end uses	Aramco, Honeywell, and King Abdullah University of Science and Technology (KAUST) joint development agreement for direct crude-to-chemicals (CTC) technology, announced October 2025, aimed at converting crude directly into light olefins and high-value chemicals rather than combustion fuel
Long-term gas infrastructure obsolescence risk	Blue hydrogen / ammonia export transition	QatarEnergy's 1.2 million-tonne-per-annum blue ammonia project at Mesaieed Industrial City, a \$1.2 billion facility incorporating CO ₂ capture and a 35 MW solar plant; ADNOC's blue ammonia supply agreements with Japan and Germany, including its first certified low-carbon ammonia shipment to Japan
Long-term hydrocarbon phase-out / narrowing demand window	Accelerated low-cost capacity monetization	ADNOC's advancement of its 5 million barrel-per-day production capacity target from 2030 to 2027, backed by a \$150 billion capital program; QatarEnergy's North Field expansion from 77 to 142 million tonnes per annum LNG capacity by 2030 (Figure 5.1)
Capital constraints on funding diversification without ceding reserve control	Minority-stake capital markets listings	Saudi Aramco's 2019 IPO and 2024 secondary offering (state retains ~97.85% ownership); ADNOC's serial subsidiary listings, including ADNOC Gas (2023), ADNOC Drilling, Borouge, and Fertiglobe, discussed in depth in Section 6.3

5.2 Reading the Table Through Real Options Theory

Each row of Table 5.1 can be read as a distinct option type in Dixit and Pindyck's (1994) framework. The crude-to-chemicals investment is a switching option: the right, not the obligation, to redirect a barrel of crude from a demand-exposed end use (transport fuel) to a less-exposed one (petrochemical feedstock) as transport demand erodes. The blue ammonia investments are growth options, relatively contained initial capital commitments (in the context of NOC balance sheets) that establish market access and technical capability which can be scaled substantially if hydrogen and ammonia demand materializes at the pace current export agreements anticipate. Accelerated capacity monetization is, paradoxically, better understood not as an option at all but as the exercise of an existing option, a decision that the value of extracting reserves now, ahead of an uncertain future demand ceiling, exceeds the option value of waiting. The minority-stake listing strategy, examined in depth in Section 6.3, is best understood as a distinct mechanism again: not an option on the underlying asset itself, but a means of monetizing a slice of the option's value without exercising or relinquishing it.

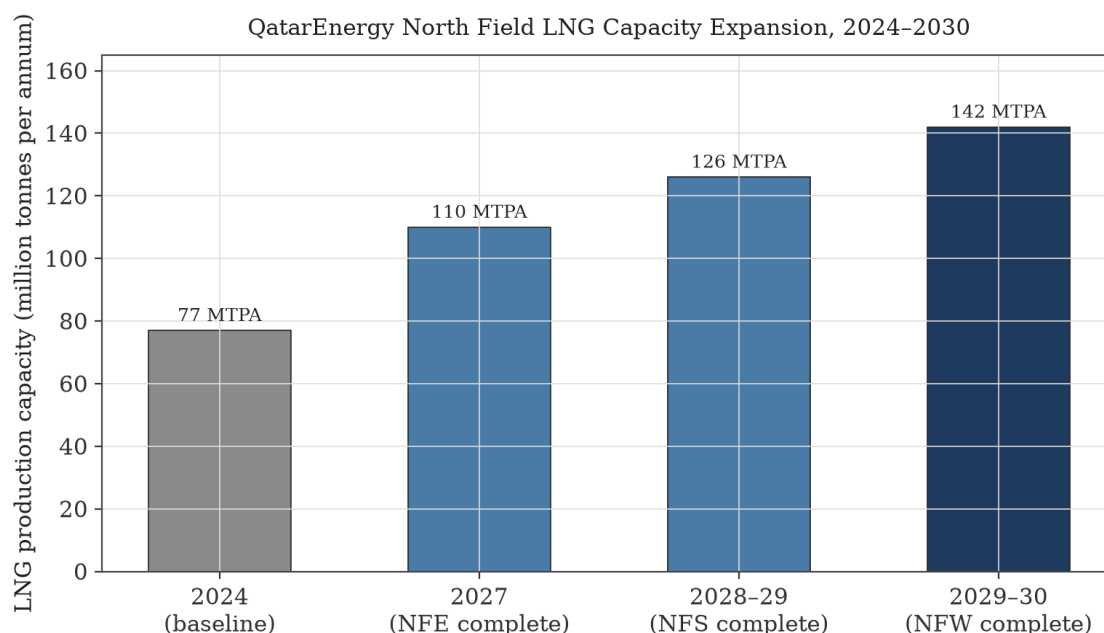
This reading directly addresses RQ2: the mechanisms are not a uniform “green pivot” but a differentiated portfolio, each calibrated to a specific, identifiable risk vector, funded by continued core-business cash flow rather than by abandoning that core business.

5.3 An Important Caveat on Scale

The capital scale of the resilience investments in Table 5.1, such as a \$1.2 billion ammonia plant, a CTC joint development agreement, and an 800,000-tonne CCUS facility, is materially smaller than the capital scale of the continued-expansion investments in the same table, such as a \$150 billion capacity program and a multi-phase LNG expansion representing one of the largest single infrastructure programs in the industry. This asymmetry is itself a finding relevant to RQ3 and is carried forward into the capital-allocation discussion in Chapter 6:

the current balance of GCC NOC capital allocation weights monetization of the existing hydrocarbon base substantially more heavily than diversification into transition-resilient infrastructure, even as both categories of investment expand in absolute terms.

Figure 5.1



Note. NFE = North Field East; NFS = North Field South; NFW = North Field West.
Source: Offshore Technology (2026); QatarEnergy North Field expansion program disclosures.

5.4 Case Study: Saudi Aramco

Aramco's resilience strategy is best characterized as options depth funded by cost leadership. Its core reserve position (approximately 268 billion barrels, produced at an estimated fully loaded cost of \$9 to \$10 per barrel) generates cash flow sufficient to fund three parallel hedges simultaneously: the Jubail CCUS hub with SLB and Linde (targeting 9 million tonnes per annum of captured CO₂ by 2027, of which Aramco's own share is 6 million tonnes), the Honeywell/KAUST crude-to-chemicals joint development agreement announced in October 2025, and continued upstream decarbonization investment more broadly. None of these three investments individually approaches the scale of Aramco's core production economics; together,

they constitute a diversified options portfolio consistent with the Real Options reading developed in Section 5.2.

Aramco's 2019 initial public offering, which raised \$25.6 billion and valued the company at \$1.7 trillion and was at the time the largest listing in history, together with a 2024 secondary offering, adds a capital-markets dimension to this picture that is examined in depth in Section 6.3. The Saudi state retains approximately 97.85% ownership and receives approximately 98% of dividends paid, with a base annual dividend commitment of \$75 to \$78 billion. The minority free float exists principally to establish a market-disciplined valuation benchmark and to channel a portion of Aramco's cash flow toward the Public Investment Fund's diversification mandate, discussed further in Section 6.5, rather than to cede meaningful operational or strategic control.

Aramco's most recent disclosures update this baseline in concrete terms. For the first quarter of 2026, the company reported capital expenditure of \$12.1 billion and guided full-year 2026 capital investment to a range of \$50.0 billion to \$55.0 billion, directed toward maintaining and expanding upstream capacity, growing gas production, and supporting downstream and chemicals projects. Two specific developments illustrate the capacity-monetization strategy documented above: start of production at the Jafurah unconventional gas field, part of a program targeting an approximately 80% increase in sales gas production capacity by 2030 relative to 2021 levels, and the East-West Pipeline's ramp-up to its maximum capacity of 7.0 million barrels per day in the first quarter of 2026, supporting crude exports via the kingdom's west coast (Aramco, 2026). The Board's declared base dividend of \$21.9 billion for the quarter, up 3.5% year-on-year despite the capital intensity of this expansion program, is consistent with the point made above that the dividend commitment functions as a floor designed to reward the 2019 and 2024 public offerings' investor base.

5.5 Case Study: ADNOC

ADNOC's resilience portfolio pursues Aramco's underlying logic, cash-funded hedging against transition risk, through a markedly different organizational structure: rather than a small number of large, flagship projects, ADNOC has spread a distributed portfolio across both technology hedges and capital-markets mechanisms. On the technology side, Al Reyadah, commissioned in partnership with Masdar, was the first commercial-scale CCUS facility in the Middle East, capturing up to 800,000 tonnes of CO₂ annually from Emirates Steel's operations for enhanced oil recovery. ADNOC has since taken a final investment decision on the larger Habshan CCUS project (1.5 million tonnes per annum, targeted for 2026), and has established blue ammonia supply relationships with buyers in Japan and Germany, including the UAE's first certified low-carbon ammonia shipment.

On the capacity side, ADNOC's acceleration of its production target, from 5 million barrels per day by 2030 to the same target by 2027, backed by a \$150 billion capital program, represents the most aggressive monetization-first move among the three companies studied, in absolute schedule-compression terms. On the capital-markets side, ADNOC has pursued the most extensive minority-listing strategy of the three NOCs, floating stakes in ADNOC Gas (2023, raising \$2.5 billion at an implied \$50 billion market capitalization, with ADNOC retaining approximately 90% ownership), ADNOC Drilling, Borouge, and Fertiglobe. This serial-listing approach, using multiple separate, smaller subsidiary floats rather than a single large parent-company listing, is examined comparatively against Aramco's single-entity approach in Section 6.3.

ADNOC's minority-listing strategy has since been extended by a structurally distinct international investment vehicle. In November 2024, ADNOC launched XRG, an international

lower-carbon energy and chemicals investment company with an enterprise value exceeding \$80 billion, which began independent operations in the first quarter of 2025 and was structured to house ADNOC's stakes in its previously separately listed subsidiaries alongside new international acquisitions. XRG's early transactions illustrate a geographic diversification distinct from the domestic capacity-expansion program discussed above: an equity position, since expanded, in NextDecade's Rio Grande LNG project in Texas; a \$16.3 billion acquisition of the German chemicals producer Covestro, in which ADNOC secured more than 91% of outstanding shares; and, together with Eni, a 32% stake in three Vaca Muerta unconventional gas blocks in Argentina alongside state operator YPF. Read through the Real Options framework, XRG extends the minority-listing logic of Section 6.3 outward rather than inward: where the ADNOC Gas, Drilling, Borouge, and Fertiglobe listings monetize a slice of domestic reserve value while retaining control, XRG deploys capital externally, building a diversified, non-GCC asset base that is, in principle, insulated from GCC-specific transition and geopolitical risk in a way the underlying domestic reserve base is not (ADNOC, 2024; The National, 2026).

5.6 Case Study: QatarEnergy

QatarEnergy's approach is the most concentrated version of the monetization-first strategy among the three cases, and it offers the clearest contrast on the capital-markets dimension. Its North Field expansion, raising LNG production capacity from 77 to 142 million tonnes per annum by 2030 across three sequential phases (North Field East, South, and West), follows confirmation of a 240 trillion cubic foot gas reserve addition that lifted Qatar's total gas reserves above 2,000 trillion cubic feet. In absolute infrastructure terms it is comparable in scale to ADNOC's oil capacity program and represents what industry commentary describes as the largest LNG expansion program in the industry's history (see Figure 5.1).

QatarEnergy's resilience-hedge investment is more concentrated than either Aramco's or ADNOC's: its principal publicly disclosed decarbonization-adjacent project is the single 1.2 million-tonne-per-annum blue ammonia facility at Mesaieed, incorporating carbon capture and a 35 megawatt solar plant to reduce the product's carbon intensity. QatarEnergy has not pursued a comparable minority-stake public listing strategy for its core LNG or upstream gas assets; the company remains wholly state-owned, without either ADNOC's serial subsidiary IPO pattern or Aramco's single-entity partial listing. This is itself a relevant finding for RQ3: it suggests that the minority-listing capital-allocation mechanism examined in Section 6.3 is not a uniform GCC NOC response to the Energy Transition Paradox, but a strategy adopted selectively, plausibly reflecting Qatar's smaller population and higher per-capita hydrocarbon wealth, which may reduce the fiscal pressure to monetize equity stakes relative to Saudi Arabia's larger population and broader Vision 2030 financing requirements. This thesis's secondary-source methodology cannot confirm that explanation directly, and it is flagged here as a plausible interpretation requiring further research rather than an established finding.

A development in the first half of 2026 supplies a direct empirical test of the distinction between demand-transition risk and exogenous geopolitical shock developed in Section 2.8. In February 2026, military conflict between the United States, Israel, and Iran resulted in an attack on QatarEnergy's Ras Laffan facility that damaged two of the country's fourteen LNG trains and one of its two gas-to-liquids facilities, taking approximately 12.8 million tonnes per annum of LNG production capacity, roughly 17% of national export capacity, offline for an expected three to five years, with an estimated \$20 billion in lost annual revenue. QatarEnergy subsequently declared force majeure on long-term supply contracts with customers including Italy, Belgium, South Korea, and China, later extending the declaration and separately halving scheduled 2026

deliveries to Bangladesh (Al Jazeera, 2026; CNBC, 2026). Rather than an anomaly outside this thesis's analytical scope, the disruption is direct empirical proof of the theoretical distinction Section 2.8 draws: it altered the strike price and timing of QatarEnergy's real options involuntarily and acutely, through physical loss of capacity, while leaving the underlying multi-decade demand for LNG, and the North Field expansion program's economic logic, unchanged. Destroyed capacity that customers still want is, if anything, the inverse of stranding, which is precisely why the two risk categories require separate treatment rather than a single combined risk framework: a facility can be simultaneously insulated from demand-transition risk, by virtue of the cost and market position documented throughout Chapter 4, and acutely exposed to geopolitical shock, as Ras Laffan demonstrates directly. The North Field expansion program itself, which subsequent reporting indicates continued despite the disruption, corroborates this separation empirically: a demand-transition-risk response would plausibly have paused or scaled back capacity investment, while a geopolitical-shock response, rebuilding damaged trains and continuing the unaffected expansion phases in parallel, is exactly what a producer facing an acute but bounded physical disruption, rather than a structural demand problem, would be expected to do.

5.7 Cross-Case Synthesis: Comparing Resilience Portfolios

Read side by side rather than sequentially, the three case studies in Sections 5.4 to 5.6 reveal a consistent structural pattern beneath their surface differences. In each case, the scale of the company's core capacity-expansion investment exceeds the scale of its resilience-hedge investment by roughly two orders of magnitude: Aramco's Jubail CCUS hub (targeting 9 million tonnes per annum by 2027) and Honeywell/KAUST crude-to-chemicals partnership sit alongside a production base measured in the hundreds of billions of dollars in annual revenue; ADNOC's

\$150 billion capacity program dwarfs its Habshan CCUS project (1.5 million tonnes per annum) and its Al Reyadah facility (800,000 tonnes per annum); QatarEnergy's single \$1.2 billion Mesaieed ammonia plant is a rounding error against a North Field expansion raising LNG capacity by 65 million tonnes per annum. This asymmetry, already flagged in Section 5.3 for each company individually, is confirmed rather than complicated by cross-case comparison: it is a feature of the sector's current strategic posture as a whole, not an idiosyncrasy of any one company's capital planning.

The three companies diverge more sharply on the capital-markets dimension examined in Section 6.3 than on the technology-hedge dimension examined here. Aramco has used the minority-listing mechanism once, at very large scale, through the parent entity; ADNOC has used it repeatedly, at smaller individual scale, through a portfolio of subsidiary floats; QatarEnergy has not used it at all for its core LNG or upstream gas assets. Because this variation does not track the companies' relative CCUS or blue-ammonia investment, which are broadly comparable across all three in proportional terms, the listing strategy and the technology-hedge strategy appear to be functionally independent choices rather than two expressions of a single underlying resilience posture: a company's appetite for external capital markets exposure is not obviously predicted by its appetite for decarbonization-technology investment. This independence is itself a modest empirical finding, since it suggests RQ2 (which technologies are deployed) and RQ3 (how capital is raised to fund them) are best analyzed as separate strategic decisions taken by GCC NOC leadership, consistent with this thesis's decision to treat them as distinct research questions rather than a single combined one.

Chapter 6: Discussion and Policy Implications

6.1 Synthesizing the Paradox

The evidence assembled in Chapters 4 and 5 supports a specific resolution of the Energy Transition Paradox rather than a simple restatement of it. The Dual-Mechanism Rentier Adaptation Model introduced in Section 2.2 organizes that resolution directly: GCC NOCs are pursuing hydrocarbon expansion and decarbonization investment simultaneously not as two expressions of one strategy but as two distinct mechanisms operating on different sides of the balance sheet. The Green Paradox governs the depletion side, documented in Chapter 4, where the cost-curve advantage gives GCC producers a longer runway than higher-cost peers to monetize reserves ahead of anticipated demand decline; Real Options Theory governs the reinvestment side, documented in Chapter 5, where current cash flow funds a portfolio of options, CCUS, crude-to-chemicals, and blue ammonia, purchased against the risk that the runway is shorter than the Current Policies scenario implies. The scale asymmetry noted in Section 5.3 is the model's own prediction made visible in the data: because the depletion mechanism generates the cash that funds the reinvestment mechanism, the hydrocarbon-monetization side of the ledger is expected to remain larger than the diversification side for as long as the reinvestment side depends on it for capital, not merely larger by historical accident.

A direct objection to this thesis's own title is worth confronting. If Real Options Theory predicts that a rational firm facing demand uncertainty should simultaneously monetize a depreciating core asset and purchase options against its decline, and the Green Paradox predicts that anticipated future constraint should accelerate that same monetization, then GCC NOC behavior is not paradoxical at all; it is the outcome both mechanisms of the Dual-Mechanism model independently predict. It would be more surprising if Aramco, ADNOC, and QatarEnergy

did not behave this way than that they do. The paradox lies one level up, in the public and policy discourse the thesis's own title borrows from, which frequently treats hydrocarbon capacity expansion and decarbonization investment as contradictory signals, evidence of insincerity or confusion, rather than as the complementary output of two well-established theoretical mechanisms. Chapter 4's correction of the conventional CBAM framing and this chapter's engagement with the minority-listing mechanism in Section 6.3 dissolve that popular-discourse paradox by showing the underlying behavior is neither contradictory nor surprising once analyzed through the Dual-Mechanism lens. Where the paradox survives scrutiny is at the sovereign level, developed in Section 6.5: a rentier state can rationally hedge its corporate exposure while leaving its fiscal exposure largely unhedged, and that gap, rather than the corporate strategy itself, is this thesis's more defensible use of the term.

6.2 Strategic Recommendations for NOC Boards

Four recommendations follow from the Real Options framing adopted in this thesis. First, capital expenditure on new infrastructure should be evaluated not only on its standalone economics but on its option value flexibility. Gas pipeline and processing infrastructure specified today with the technical capacity to carry hydrogen or ammonia in the future preserves optionality at comparatively low incremental cost relative to retrofitting later, a principle consistent with Dixit and Pindyck's (1994) emphasis on the value of preserving flexibility under uncertainty. In practice this means investment committees should require an explicit optionality assessment alongside the standard net-present-value case for major infrastructure decisions, quantifying, even approximately, the cost of building in future-proofing today against the cost of retrofitting or stranding the asset later, rather than treating flexibility as a qualitative afterthought to a purely NPV-driven decision.

Second, boards should treat the current CBAM correction identified in Section 4.2 as an early-warning indicator rather than a reason for complacency: fertilizer-sector exposure today is a preview of the compliance and carbon-accounting infrastructure that will be required if petrochemical coverage expands toward 2030, and building that infrastructure ahead of mandatory coverage is itself an option worth purchasing early. This recommendation gains force from a demand-side finding largely external to this thesis's own modeling: the IEA's Oil 2025 outlook projects that petrochemical feedstocks will rise from 15.8% of total oil consumption in 2023 to 17.4% by 2030, accounting for more than a third of total oil demand growth to 2030 and nearly half to 2050, and becoming the dominant source of oil demand growth from 2026 onward as combustion-fuel demand plateaus (IEA, 2025a). This projection strengthens the strategic logic behind Aramco's crude-to-chemicals investment documented in Section 5.4: petrochemical feedstock demand is not merely a defensive hedge against the transport-fuel displacement risk framed in Section 4.3, but a growth segment in its own right, which should inform how boards prioritize crude-to-chemicals conversion relative to other resilience investments competing for the same capital.

Third, the capital allocation asymmetry documented in Section 5.3 and confirmed across all three companies in Section 5.7 warrants explicit board-level tracking, not necessarily rebalancing, given the legitimate logic of funding diversification from core-business cash flow, but visibility into whether the ratio of monetization to diversification capital is a deliberate, revisited strategic choice or simply the default outcome of near-term project economics.

Fourth, boards should treat the minority-listing mechanism analyzed in Section 6.3 and the disclosure obligations it carries, discussed in Section 6.4, as a linked decision rather than two separate workstreams handled by different parts of the organization. A subsidiary float decided

primarily on capital-raising grounds, without early alignment between finance, investor relations, and the technical teams that would need to produce TCFD-aligned reserve and emissions data, risks a listing that undershoots the disclosure standard the market increasingly expects, which is a reputational and valuation risk distinct from, but compounding, the stranded-asset risk this thesis analyzes throughout.

6.3 Capital Markets as a Resilience Mechanism: The Minority-Stake Listing Strategy

The case studies in Sections 5.4 and 5.5 surface a capital-allocation mechanism directly relevant to RQ3 that receives comparatively little attention in either the stranded-asset or GCC energy-policy literatures reviewed in Chapter 2: the practice of listing a minority equity stake in a hydrocarbon-linked entity on public markets, while retaining majority, often supermajority, state ownership and full operational control.

Aramco's 2019 initial public offering sold approximately 1.5% of total share capital for \$25.6 billion, and a 2024 secondary offering added to the public float. The Saudi state, through the Ministry of Finance and the Public Investment Fund, retains approximately 97.85% ownership and receives approximately 98% of dividends paid, with a base annual dividend of \$75 to \$78 billion designed to reward IPO investors while preserving government revenue as a floor. ADNOC has pursued a structurally similar but organizationally distinct approach. Rather than listing a small stake in the parent entity, it has floated minority stakes in a series of separate subsidiaries, including ADNOC Gas (2023, raising \$2.5 billion at an implied \$50 billion valuation, with ADNOC retaining approximately 90%), ADNOC Drilling, the petrochemicals joint venture Borouge, and the fertilizer joint venture Fertiglobe.

Read through the Real Options framework adopted in Chapter 3, this mechanism is best understood as a means of monetizing a slice of the value of the underlying real option (the

reserve base and its associated future cash flows) without exercising or relinquishing the option itself. A conventional asset sale would convert reserves into cash but surrender future upside and strategic control over production decisions; continued 100%-state-owned operation preserves full option value but generates no external capital beyond retained earnings and debt issuance. The minority listing sits between these two extremes: it converts a small, bounded slice of future cash-flow value into large, immediate capital, precisely the capital Chapter 2's rentier-state analysis identifies as necessary to fund diversification without new domestic taxation, while the state's retained supermajority preserves full control over the reserve base, production timing, and the very real options (CCUS, CTC, and blue ammonia investment decisions) analyzed in Chapter 5.

This finding also refines RQ3 empirically rather than only theoretically. The three companies studied do not apply this mechanism uniformly: Aramco has used it once, at very large individual scale, through the parent entity itself; ADNOC has used it repeatedly, at smaller individual scale, through a portfolio of subsidiaries, arguably diversifying its capital-raising risk and creating multiple independently tradeable equity benchmarks; QatarEnergy, as discussed in Section 5.6, has not used it at all for its core assets. This variation suggests the minority-listing mechanism is a strategic choice shaped by firm- and state-specific factors, such as population size, existing sovereign wealth fund scale, and domestic capital market depth, rather than a deterministic response to the Energy Transition Paradox common to all GCC NOCs. It represents a specific, evidence-grounded answer to RQ3 that goes beyond the more general observation, made in Section 6.1, that capital allocation is currently weighted toward monetization over diversification.

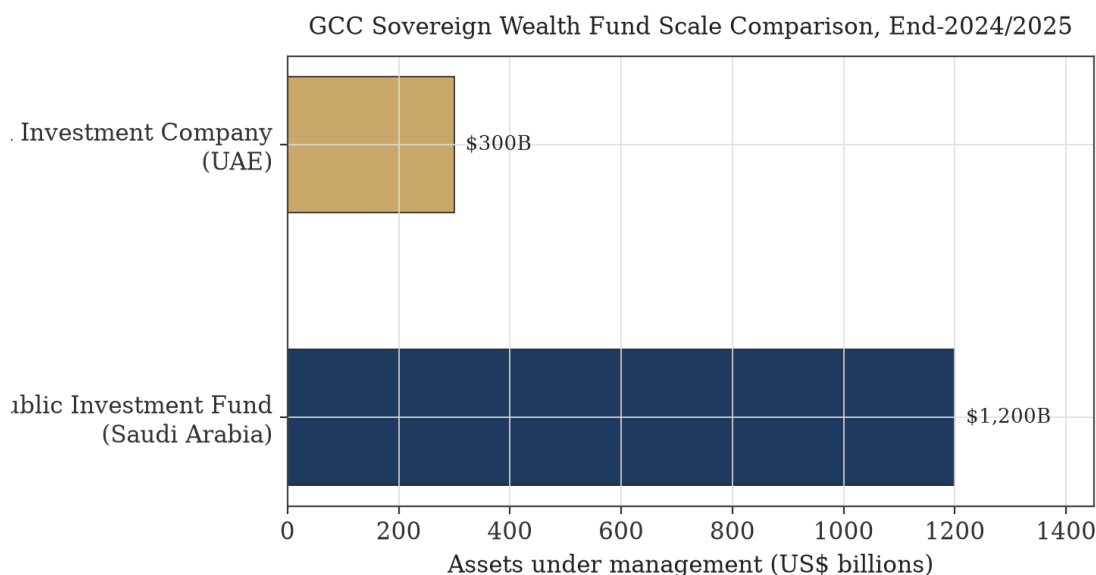
6.4 Disclosure as a Second-Order Resilience Mechanism

The minority-stake listing mechanism examined in Section 6.3 has a second function beyond capital raising that the capital-allocation framing above does not fully capture: it is also, functionally, a disclosure mechanism. Section 2.6 situated the stranded-asset concept within the broader financial-regulatory movement toward standardized climate risk disclosure, catalyzed by Carney's (2015) Tragedy of the Horizon speech and formalized in the Task Force on Climate-related Financial Disclosures' (2017) four-pillar framework. Publicly listed entities, including the minority-owned subsidiaries ADNOC has floated and the Aramco parent entity itself, face materially different disclosure expectations from wholly state-owned operating companies, both because stock exchange listing rules increasingly require climate-related disclosure directly and because the institutional investors who purchase minority stakes increasingly demand TCFD-aligned reporting as a condition of continued or expanded investment.

Read against the rentier state framing developed in Section 2.3, this exemption is better understood as a deliberate structural feature of state ownership than as a passive gap awaiting future regulatory catch-up. A wholly state-owned NOC that never accesses public equity markets faces no external mechanism forcing TCFD-aligned reserve and cost disclosure, and that absence of pressure is not incidental: it insulates the sovereign reserve base from the disorderly repricing event Carney's (2015) Tragedy of the Horizon speech warns a mispriced transition risk eventually produces. Opacity, on this reading, functions as a second-order resilience mechanism in its own right, a shield against climate-liability repricing that operates independently of the technology and monetization hedges examined in Chapter 5, for as long as the state chooses not to seek public capital. The minority-listing mechanism examined in Section 6.3 is significant precisely because it is the one channel through which this shield erodes on the state's own initiative: each subsidiary float voluntarily imports the disclosure obligations the parent reserve

base itself remains exempt from, trading a slice of the opacity shield for the capital-raising and market-benchmark benefits documented in Section 6.3. Convergence toward TCFD-level disclosure is accordingly a function of how far and how fast GCC NOCs choose to extend public capital markets access, not an inevitability driven by external regulatory pressure alone.

This creates a specific, testable implication that follows from, but goes beyond, this thesis's own data limitations. As documented in Section 3.5, this thesis's own quantitative model was constrained throughout by GCC NOCs' comparatively limited disclosure of reserve valuation methodology and asset-level cost data relative to SEC-registered IOCs. If the minority-listing mechanism continues to expand, as ADNOC's serial subsidiary listings suggest it might, the disclosure obligations attached to each new listing should incrementally narrow exactly this gap, entity by entity, even though the majority-owned parent reserve base itself remains outside any disclosure requirement triggered only by a minority float. The practical implication for future researchers, and for this thesis's own Appendix A model, is that the more precise, less proxy-dependent successor study flagged in Section 7.3 is not purely hypothetical: it becomes progressively more feasible with each additional GCC NOC subsidiary listing, in a way that is at least partly observable and trackable now, rather than reserved entirely for scholarship a decade from now.

Figure 6.1

Note. PIF figure reflects reported 2024 year-end assets (~18% growth); Mubadala figure is an approximate reported AUM. Both are third-party/press-reported figures, not audited disclosures. Source: Forbes Middle East (2026).

6.5 Macroeconomic Implications for GCC States

At the sovereign level, the same paradox reappears in fiscal form: state budgets remain substantially funded by hydrocarbon revenue, while sovereign wealth funds financed by that same revenue, and, as Section 6.3 shows, increasingly by minority-stake listing proceeds specifically, pursue the diversification intended to eventually replace it. Saudi Arabia's Public Investment Fund, with assets that grew 18% to approximately \$1.2 trillion by the end of 2024, concentrates over 60% of its portfolio domestically in pursuit of Vision 2030 diversification projects, while the UAE's Mubadala Investment Company, formed through the 2017 merger with the International Petroleum Investment Company, pursues a more globally diversified, internationally balanced portfolio of roughly \$300 billion (Forbes Middle East, 2026), illustrated in Figure 6.1. Both models represent a form of sovereign-level hedging against the same stranded-asset risk examined at the corporate level in this thesis, and the divergence between PIF's domestic-concentration approach and Mubadala's global-diversification approach is itself a

meaningful natural comparison for future research, extended in Section 6.6 and discussed further in Chapter 7.

ADNOC's XRG vehicle, documented in Section 5.5, adds a third model to this comparison that is corporate rather than sovereign in form: XRG deploys ADNOC's own capital internationally, rather than capital already transferred to a separate sovereign wealth fund. This blurs a distinction this chapter has otherwise treated as reasonably clean, between NOC capital allocation and SWF capital allocation, and it suggests that the corporate-sovereign boundary within the UAE's capital-allocation architecture specifically is less firm than the PIF/Mubadala comparison alone would imply. Whether XRG represents a new capital-allocation category or simply a relabeling of activity a sovereign wealth fund would otherwise have undertaken is a question this thesis's secondary-source methodology cannot resolve, and it is flagged here as a limitation of the corporate/sovereign framing adopted in this chapter rather than resolved.

A brief observation for state budget policy, informed by the rentier state framing developed in Chapter 2: to the extent that stranded-asset risk is a multi-decade, low-but-nonzero-probability tail risk, the degree to which state budgets are decoupled from oil price and volume volatility today is a more direct sovereign-level hedge than SWF portfolio diversification alone, since the latter depends on continued oil revenue, and, per Section 6.3, continued minority-listing proceeds, to fund it. A rentier state that has diversified its investment portfolio but not its fiscal base has hedged its assets without hedging its income statement.

6.6 Comparative Perspective: Sovereign Hedging Models Beyond the GCC

Section 6.5's contrast between the Public Investment Fund's domestic-concentration model and Mubadala's globally diversified model can be sharpened by situating both against a third, structurally different sovereign approach to hydrocarbon-linked wealth: Norway's

Government Pension Fund Global. Unlike PIF and Mubadala, which retain and in some cases increase exposure to hydrocarbon-linked equities and to the NOCs' own capital-raising activity documented in Section 6.3, Norway's Ministry of Finance in 2019 recommended, and Norges Bank subsequently implemented, divestment of the fund's roughly \$7.5 billion in holdings of pure-play oil and gas exploration and production companies, retaining exposure only to integrated majors with substantial non-fossil-fuel business lines (Norwegian Ministry of Finance, 2019). The explicit rationale was risk concentration rather than climate policy per se: a state whose national income is itself heavily oil-linked, as Norway's is, should not compound that concentration by also holding its financial reserves in oil-price-correlated equities, a logic that applies with at least equal force to Saudi Arabia, the UAE, and Qatar.

That GCC sovereign wealth funds have not followed Norway's divestment logic, despite facing an arguably starker version of the same concentration risk, is itself informative when read through the rentier state theory developed in Section 2.3. Norway's fiscal base is diversified enough, and its state institutions developed enough in Karl's (1997) sense, to treat the pension fund's investment portfolio as separable from near-term state revenue; the fund exists explicitly to convert a depleting resource into a permanent, generationally transferable financial asset, and reducing correlated risk within that asset is a coherent objective on its own terms. PIF and Mubadala, by contrast, remain instruments of active, near-term economic diversification policy, per Section 6.5, not primarily vehicles for intergenerational wealth preservation, which makes continued exposure to oil-linked capital markets activity, including the NOC listings each fund helps structure, a feature of their mandate rather than a risk to be hedged away. The comparison does not establish which model is superior; it establishes that the difference is a considered consequence of each state's fiscal structure and policy objectives rather than an oversight, and it

sharpens, rather than resolves, the future research question flagged in Section 7.3 regarding which model constitutes the more effective long-run hedge against stranded-asset risk.

6.7 Summary of Findings by Research Question

Table 6.1 consolidates the thesis's findings against each research question, drawing together results from Chapters 4, 5, and this chapter.

Table 6.1 *Summary of Findings by Research Question*

Research Question	Key Finding
RQ1: Financial exposure under IEA scenarios, GCC vs. IOCs	GCC NOCs' low-cost position provides a materially different, more insulated exposure profile than higher-cost IOCs, but the advantage is relative and time-limited, not immunity. Illustrative modeling estimates Aramco's 25-year reserve margin value at \$2.1 to \$3.4 trillion and ADNOC's at \$0.7 to \$1.2 trillion across IEA scenarios, with ADNOC's proportionally larger sensitivity reflecting both real economics and a data-opacity-driven cost-proxy limitation.
RQ2: Strategic resilience mechanisms and their risk mapping	GCC NOCs deploy a differentiated real-options portfolio, including CCUS (Al Reyadah, Habshan, Jubail), crude-to-chemicals (Aramco/Honeywell/KAUST), and blue ammonia (QatarEnergy Mesaieed, ADNOC Japan/Germany shipments), each mapped to a specific risk vector and funded by, and currently smaller in scale than, continued core capacity expansion.
RQ3: Capital allocation tension between monetization and stranding risk	A previously under-examined mechanism, minority-stake capital markets listings (Aramco's IPO/secondary offering; ADNOC's serial subsidiary listings), allows GCC NOCs to monetize a slice of reserve value to fund diversification while retaining majority control of the underlying reserve base. This mechanism is applied unevenly across the three companies studied (heavily by ADNOC, once by Aramco, not at all by QatarEnergy), indicating firm- and state-specific rather than uniform GCC-wide capital allocation behavior.

Chapter 7: Conclusion

7.1 Summary of Findings

This thesis set out to examine how GCC national oil companies are positioned relative to, and are responding to, stranded-asset risk under the global energy transition. This is a question the existing literature has addressed extensively for higher-cost Western IOCs but has not adequately theorized for low-cost, state-backed GCC producers. Four findings stand out, summarized in Table 6.1. First, GCC NOCs occupy a structurally different risk position than the IOC population that dominates existing stranded-asset scholarship: their position at the low-cost end of the global cost curve means they are, on cost grounds alone, the least likely reserves to be stranded first, though this is a relative and time-limited advantage rather than immunity. Second, a widely repeated claim in popular commentary, that the EU's Carbon Border Adjustment Mechanism currently penalizes GCC oil and gas exports, does not hold as stated; current CBAM exposure is real but concentrated in fertilizer and ammonia trade, with broader petrochemical exposure anticipated closer to 2030. Third, GCC NOC strategic-resilience investment is best understood through Real Options Theory as a differentiated portfolio of options purchased against specific, identifiable risk vectors, funded by and substantially smaller in scale than continued core hydrocarbon capacity expansion. Fourth, and least examined in the existing literature, GCC NOCs increasingly fund diversification through minority-stake capital markets listings that monetize a bounded slice of reserve value while preserving majority state control, a mechanism applied unevenly across Aramco, ADNOC, and QatarEnergy in ways that reflect firm- and state-specific circumstances rather than a uniform regional strategy.

7.2 Contribution to Knowledge

This thesis contributes to the stranded-asset literature in three specific ways. Empirically, it provides an illustrative but methodologically transparent scenario-based exposure estimate for two major GCC NOCs, a population largely absent from the quantitative stranded-asset literature to date. Theoretically, it extends Real Options Theory's established application to petroleum decommissioning timing (Abdul-Salam, 2022) to a broader portfolio of GCC strategic-resilience investments, and connects this financial framework explicitly to rentier state theory (Beblawi & Luciani, 1987) to explain why stranded-asset risk in this specific context is inseparable from sovereign fiscal risk. Empirically again, it identifies and documents the minority-stake listing mechanism as a capital-allocation response to the Energy Transition Paradox that has not, to this thesis's knowledge, been analyzed through a stranded-asset or real-options lens in the existing literature reviewed in Chapter 2.

Beyond these academic contributions, this thesis offers a practical contribution distinct from its scholarly one. The board-level recommendations developed in Section 6.2, the disclosure-mechanism analysis in Section 6.4, and the sovereign-comparison framework in Section 6.6 are written to be directly usable by GCC NOC strategy and investor-relations functions, and by the sovereign wealth funds these NOCs increasingly help capitalize, independent of whether the reader accepts every element of this thesis's academic argument. This dual audience, academic and practitioner, reflects the applied character of the stranded-asset literature itself, which has always sat closer to financial practice than most academic finance subfields, and this thesis is written with that dual readership in mind throughout.

7.3 Avenues for Future Research

Three limitations of this thesis point directly to future research directions. First, the sovereign wealth fund comparison introduced in Section 6.5 and extended to Norway's

contrasting divestment-based model in Section 6.6, PIF's domestic-concentration diversification model against Mubadala's globally diversified model against Norway's Government Pension Fund Global's direct divestment from oil and gas exploration equities, deserves treatment as a primary, quantitative research question in its own right rather than the qualitative comparative discussion offered here: which model constitutes a more effective sovereign-level hedge against stranded-asset risk, measured in realized risk-adjusted returns rather than portfolio composition alone, is an open, empirically tractable question given the public portfolio disclosure all three funds provide, to varying degrees. Second, the data-opacity limitation stated in Chapter 3, the absence of disclosed reserve valuation methodology for GCC NOCs comparable to SEC-mandated disclosure for US-listed IOCs, is itself a research opportunity: as GCC NOCs increasingly access international capital markets through the minority-listing mechanism identified in Section 6.3, the TCFD-aligned disclosure requirements discussed in Section 6.4 and attached to that market access may over time generate the primary data this thesis's quantitative phase was structurally unable to access, enabling a materially more precise successor study. Third, the uneven adoption of the minority-listing strategy identified in Section 6.3, pursued extensively by ADNOC, once by Aramco, and not at all by QatarEnergy, warrants dedicated comparative research into the state-level factors (population, existing sovereign wealth, domestic capital market depth) that this thesis's secondary-source methodology could identify as plausible but could not test directly. Fourth, the COP29 and COP30 pattern documented in Section 1.1 and the Green Paradox tension developed in Section 2.2 together suggest a specific, empirically tractable test for future research: whether GCC NOC capital expenditure timing, as more granular data becomes available through the disclosure channel discussed in Section 6.4, correlates more closely with the credibility of specific multilateral climate commitments than

with oil-price cycles alone. Such a test would move the Green Paradox from a theoretical possibility this thesis can only motivate qualitatively to an empirically evaluated mechanism.

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Appendix A: Scenario Exposure Model Assumptions and Outputs

This appendix reproduces the full assumption set and numerical outputs underlying the scenario-based exposure model presented in Section 3.4 and Chapter 4, for transparency and replicability. As described in Section 3.4, the model is run under two production-volume bookends for each company, Model A and Model B, rather than a single production path.

A.1 Model Assumptions

Discount rate: 8% (nominal, annual)

Analysis horizon: 25 years (2026 to 2050), matching IEA (2025) modeling horizon

Valuation method: ordinary annuity of estimated annual upstream margin, held flat across the horizon within each scenario

Model A (cost-curve-protected bookend): annual production held constant across all three price scenarios

Model B (demand-proportional bookend): annual production scaled by the ratio of 2050 to present-day global oil demand under the same scenario, using a demand factor of approximately 1.10 for Current Policies, 0.99 for Stated Policies, and 0.25 for Net Zero Emissions (IEA, 2025b, 2026; U.S. EIA, 2026)

Saudi Aramco: estimated production 10.0 million barrels/day; estimated fully loaded upstream cost band \$9 to \$10/barrel (Arab News, 2019)

ADNOC: estimated production 4.5 million barrels/day (average toward 2027 target); cost band \$15 to \$27/barrel, with the upper bound anchored to the regional Middle East onshore breakeven proxy (no company-specific figure disclosed; see Sections 3.4 and 4.4 for discussion of this limitation)

ExxonMobil (IOC benchmark): estimated production 3.0 million barrels/day, consistent with the 3.329 million barrels/day the company reported for full-year 2025 (ExxonMobil, 2026); company-stated 2030 breakeven cost target \$30/barrel, a forward-looking target rather than a currently disclosed actual cost

Price scenarios: Current Policies $\approx$ \$96/bbl; Stated Policies $\approx$ \$80/bbl; Net Zero Emissions $\approx$ \$65/bbl (derived from IEA, 2025b; U.S. EIA, 2026; International Energy Forum, 2026)

A.2 Model Outputs (US\$ billions, 25-year NPV of upstream margin)

Saudi Aramco

Current Policies: Model A \$3,370B (cost-band range \$3,351B to \$3,390B) | Model B \$3,698B

Stated Policies: Model A \$2,747B (cost-band range \$2,727B to \$2,766B) | Model B \$2,720B

Net Zero Emissions: Model A \$2,162B (cost-band range \$2,143B to \$2,182B) | Model B \$541B

ADNOC

Current Policies: Model A \$1,315B (cost-band range \$1,210B to \$1,420B) | Model B \$1,443B

Stated Policies: Model A \$1,034B (cost-band range \$929B to \$1,140B) | Model B \$1,024B

Net Zero Emissions: Model A \$771B (cost-band range \$666B to \$877B) | Model B \$193B

ExxonMobil (IOC Benchmark)

Current Policies: Model A \$771B | Model B \$846B

Stated Policies: Model A \$584B | Model B \$579B

Net Zero Emissions: Model A \$409B | Model B \$102B

These figures are illustrative order-of-magnitude estimates, not audited or company-disclosed valuations. Model A results are reproducible from the assumptions listed above using the ordinary annuity formula $NPV = [(Price - Cost) \times Annual Production] \times [(1 - (1 + r)^{-T}) / r]$, with $r = 0.08$ and $T = 25$. Model B applies the same formula but multiplies Annual Production by the company- and scenario-specific demand factor listed in A.1 before discounting. Cost-band ranges for Aramco and ADNOC reflect the low and high ends of each company's estimated cost

range applied to the same production and price assumptions; ExxonMobil's single-point cost target produces no comparable range.

A.3 Companion Spreadsheet

The full model, including live formulas for both Model A and Model B across all three companies and all three price scenarios, is reproduced in the companion spreadsheet `GCC_Stranded_Asset_DCF_Model.xlsx`, distributed alongside this thesis. The spreadsheet allows a reader to vary any input assumption, including price, cost, production volume, demand factor, or discount rate, and observe the resulting change in estimated exposure directly, without recomputing the annuity formula by hand.