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# Economic Optimization of Petroleum Engineering Projects -A Review

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***Abstract-*** ***Upstream petroleum projects increasingly operate under simultaneous exposure to commodity price uncertainty, carbon cost internalisation, and evolving environmental regulation, requiring a quantitatively robust approach to economic optimisation. This study formulates a value-maximisation framework that integrates petroleum engineering design variables with stochastic energy-economic drivers and emissions constraints. Project revenues and costs are simulated under uncertain oil market conditions and policy-driven carbon pricing pathways, while greenhouse gas emissions are explicitly represented through asset-level emissions intensity coefficients. The optimisation problem is constructed to maximise certainty-equivalent net present value by jointly selecting development scale, production profiles, and investment timing, subject to technical, financial, and emissions-related constraints. Regulatory risk and managerial flexibility are captured using option-based valuation embedded within a Monte Carlo simulation environment. Numerical experiments across alternative carbon price trajectories demonstrate that ignoring emissions costs leads to systematically biased investment decisions and lower risk-adjusted returns. Results indicate that development strategies emphasising operational flexibility and reduced emissions intensity outperform conventional designs under stringent climate policy scenarios. The proposed methodology provides a rigorous quantitative bridge between petroleum engineering optimisation and energy economics, offering decision-relevant insights for capital allocation, regulatory resilience, and sustainable upstream development.***

***Keywords: - Economic Aspect of Petroleum Industry, Optimization Technique, Marketing Decision and Planning in Petroleum Industry, NPV Maximization, IRR Improvement, Field Development Planning, Strategic Formulation in Petroleum Industry, Hedging Strategies for Economics in Petroleum Engineering Projects***

## I. INTRODUCTION

The Economic problem of petroleum industry generally depends on consumer desires, objective of the oil firm which may be unlimited or prioritised and to find out the solution of that problem may be limited or unlimited. In oil industry the firm may be try to maximize the level of output within a fixed budgetary outlay or minimise the cost of production for a targeted rate of output which is termed as "Constrained optimisation ". These constrains may be internal or external factor. The internal factor on which companies working for namely limited availability of land where oil rig has explored the oil, limited labour of drilling crew, geologist and seismologist, working capital manageability whereas external factor mainly is politico-legal constrains regulation of internal bodies like OPEC IEA, EUMR, FERC, EPA, BLM. To find out the solution of those constrained optimization factor oil industry should study the market analysis , aggregate demand and supply analysis , general price level oil and related product, individual consumer demand of that particular oil product and individual consumer income from that particular oil product .For decision making to solute the problem first we have to establish the objective -define the problem-identify the alternatives-select the best alternatives-implement the decision . For an example the best decision will be taken when produce oil if marginal revenue oil (price)≥marginal cost of extract the oil and those decisions are optimal when marginal benefit =marginal cost. To deduct the marginal cost oil in this paper we generally use the formula $MC = \Delta TC/\Delta Q$, where $\Delta TC$ is the change in the total cost and $\Delta Q$ is the change in quantity produced .in Oilfield every operational manager should consider both short and long run of a project that is time duration and also, we can choose the discounting principal theory in our paper and according to which FV(Future value of money in oil and gas project)= PV (Present value of money in oil and gas project )* (1+r)^n , where r=discount rate at which oil company sold their product , n= number of years in which we are calculated our product value . In our paper we will also discuss supply and demand oil and gas industry product by analysing price of that particular oil product by plotting against quantity demanded per week of that particular product and also, we calculate is there any shift in demand by calculating whether there will be increase or decrease of that particular oil product by calculating perpetuity and annuity of that particular product, by those following formula

Perpetuity (P)= C/ r where C= Annual cash flow and r= discount rate

Annuity (A) = C*[(1-(1+r) $^{n}$)/r], where C= payment per period, r=discount rate, n= number of periods

In our paper we will also discuss about which factor may cause in the shift of demand of oil and gas product like energy transition, that is moving from fossil fuels to renewables, LNG growth that is increased liquified natural gas trade and electrification like impact on oil demand, that Electrical vehicle reducing oil demand. In our research paper we will also study the "Market Equilibrium condition "from 2000 to 2025 by gathering data of oil price and how much how much oil has been supplied in that year, and plot the quantity vs demand curve and find the equilibrium condition from the year 2000 to 2025 year. To find out an ideal solution of oil and gas management, we use in our paper BGC MATRIX, ANSOFF MATRIX, Porter's five forces analysis etc to find out ideal condition in which the market condition oil and gas company sold their product as the "Market equilibrium "can only be achieved when quantity of oil demand is equal to the quantity of oil has been supplied.

We also apply the "Hotelling rule "in 2000-2025 oil prices, to optimise extraction timing, guide oil companies on investment strategies and understand how scarcity drives prices of oil & gas and make a good extraction decision for oil companies. Not only that, in this paper we also calculate the "Price elasticity " of oil price to set up the pricing strategy, policy impact and making some business decision for oil companies for future use and also we calculate "Income elasticity " of people of India, so that we can say the oil is necessary or is a luxury for Indian civilization and for further clarification we generate " Cross price elasticity model'' to understand which product can substitute oil and we will also elaborate why it substitutable as now a days there is a scenario of decarbonization technique and dependency on renewable energy, CCUS (Carbon capture and storage ) and carbon Taxes.

In our paper, we will also work on a case study "Regarding the production function for long run and short run of an oil exploration project '' and analyse how much labour has been input vs their output in an oil project and in that project, we will draw a "Isocost line " to determine combination of labour and capital that can be that be purchased for a given amount of total cost of a project. The main motive of that case study is to give the firm his own expansion path. In this Case study, we also use "Material Balance Equation "

## II. BACKGROUND OF THE STUDY

The "Economic optimisation of petroleum engineering project "plays a crucial role in the oil and gas industry due to the high volatility of oil prices, geological uncertainty and high capital intensity. From 2000 to 2025, the oil price has been significantly volatile due to shifts in global demand, economic crisis due to COVID-19, the Russia-Ukraine war, the global financial crisis (2007-2009), which was triggered by the US government, subprime mortgage collapse, and also the Earlier crisis like Asian financial crisis (1997-1998), the effect of Dot -Com bubble, which was held up by early 2000 a period of extreme speculation in internet-based companies (dot-coms), Investors poured money into startups with ".com" business models, often ignoring profitability or revenue, betting on rapid growth and future dominance in the digital

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economy. Many companies went for bankrupt, and NASDAQ lost nearly 78 % of its value by 2002. The earlier Black Monday event, which refers global stock of market crash that occurred on October 19.1987 when the stock market plummeted within a single day, and oil prices also fall down in that day.

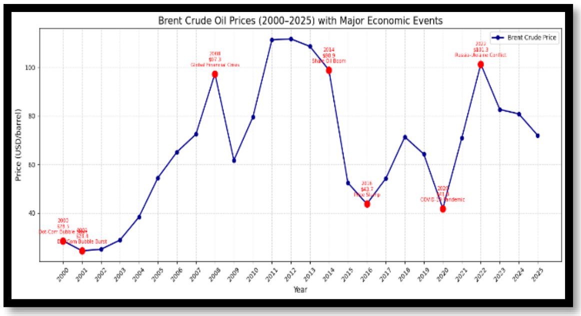


Fig 1 :- Brent crude oil graph from (2000-2025 ) with major annotation of major economic events

Note:-"Brent crude oil prices from 2000 to 2025 with major economic events marked in red, showing how global financial and geopolitical crises influenced price volatility."

Our paper examines the major economic principles, financial models and some decision -making tools to optimise upstream, midstream and downstream across the world exploration, development and production phases. Key optimisation techniques, such as Time Value of Money (TVM), Market equilibrium condition calculation, apply "Hotelling rule "in 2000-2025 oil prices, to optimise extraction timing, guide oil companies on investment strategies, calculating "Isocost line'' to determine combination of labour and capital that can be that be purchased for a given amount of total cost of a project. Not only that in our paper, we also examine " Demand elasticity " of oil from 2000 to 2025 and also calculate "Income elasticity " of the people in India of different states so that we can say oil is necessary or luxury for Indian people and if it is luxury we also generate " Cross -price elasticity model "to understand which product can substitute oil and we also explain here why it will substitutable. Not only that we also arrange a case study regarding the production function for the short run and long run for an oil project to analyse how much labour has been input vs their output by using the Cobb–Douglas production function method for the long run and short run of an oil project. Not only that, the paper additionally evaluates the mixing of engineering fashions—along with production capabilities, reservoir material stability, and decline curve evaluation—with financial evaluation strategies. moreover, the examine highlights the effect of oil rate uncertainty, technological development, and sustainability concerns on task economics. The review concludes by means of identifying rising tendencies and research gaps in financial optimization underneath the evolving international strength landscape.

## III. AIM OF THE STUDY

The aim of the study "Economic Optimization of Petroleum Engineering Projects -A Review'' is to give every petroleum company optimize production and maximize recovery while manging total cost. effective managing risks associated with price risks associated with price volatility and regulatory changes. The study also seeks to evaluate investments, prioritize projects, and allocate capital efficiency, with a focus on enhancing operational efficiency and reducing opex. Additionally, it aims to balance sustainability goals with environmental impact, exploring digital transformation and innovative strategies to ensure petroleum companies long -term viability in a rapidly and fast-growing energy landscape of petroleum industry Key areas of focus include assessing the impact of energy transition on portfolio residence, identifying opportunities for cost reduction in petroleum engineering projects and operational excellence, and developing a data driven decision making frameworks to drive business growth and profitability. By achieving these objectives, petroleum companies can enhance its competitive position, drive shareholder value and maintain social license to operate the petroleum engineering projects. Exploring digital transformation and many innovative technologies like AI, IOT and advanced analytics to

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drive business growth opportunities and give a profitable situation to petroleum companies. The study will also examine economic indicators like NPV, IRR and break -even prices to ensure project viability, while leveraging technologies like advanced cloud computing, big data and machine learning algorithm also been unlocked for new value streams and improved competitiveness for petroleum engineering projects.

## IV. METHODOLOGY

The methodology here has been described the following manner

A) Apply the theory of "Constrained optimisation: - Generally ", Constrained optimisation" has been described as Restricted optimisation in the oil and gas enterprise, which is the process of maximising economic or technical overall performance of hydrocarbon assets while satisfying physical, operational, financial, and environmental constraints.

Mathematical concept of "Constrained optimisation: - In mathematical terms, constrained optimization seeks to:

$$\max_{x} \; f(x) \text{subject to} g_i(x) \le 0,\; h_j(x) = 0$$

Where:

- $f(x)$: objective function (e.g., NPV, IRR, recovery factor, profit)
- $g_i(x)$: inequality constraints (capacity, emissions limits, budget)
- $h_j(x)$: equality constraints (material balance, flow conservation)

## V. CALCULATION

Brent Crude Oil Annual Average Price (USD per Barrel) 2000–2025

| Year | Avg. Brent Price ($/bbl) |
|---|---|
| 2000 | 28.40 |
| 2001 | 24.45 |
| 2002 | 25.01 |
| 2003 | 28.83 |
| 2004 | 38.10 |
| 2005 | 54.38 |
| 2006 | 65.14 |
| 2007 | 72.52 |
| 2008 | 96.99 |
| 2009 | 61.51 |
| 2010 | 79.47 |
| 2011 | 111.26 |
| 2012 | 111.63 |
| 2013 | 108.56 |
| 2014 | 98.97 |
| 2015 | 52.32 |
| 2016 | 43.67 |
| 2017 | 54.25 |
| 2018 | 71.34 |
| 2019 | 64.30 |
| 2020 | 41.96 |
| 2021 | 70.86 |
| 2022 | 100.93 |
| 2023 | 82.49 |
| 2024 | ~80–82* |
| 2025 | ~71.9* |

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Table 1 :- Brent Crude Oil Annual Average Price (USD per Barrel) 2000–2025

1. Problem Setup (Oil & Gas Context):-

Assume an upstream oil project producing a constant quantity $Q$per year.

Objective (Economic)

Maximise Net Present Value (NPV):

$$\max_{Q} \; f(Q) = \sum_{t=1}^{T} \frac{(P_t Q - CQ)}{(1+r)^t}$$

Where:

- $P_t$= oil price (USD/bbl)
- $Q$= annual production (million bbl/year)
- $C$= operating cost per barrel
- $r$= discount rate
- $T$= project life

2. Real-World Data (Simplified)

Use the average Brent oil price (2000–2025 mean):

$\bar{P} \approx 66$ USD/bbl

Assume:

- $C = 30$USD/bbl
- $r = 8\%$
- $T = 25$years
- Discount factor sum:

$$\sum_{t=1}^{25} \frac{1}{(1+0.08)^t} \approx 9.82$$

Note:- Why Operating Cost C = 30 USD/bbl? Industry Reality (2000–2025) :-

For conventional and moderately complex upstream projects:-

| Project Type | Typical OPEX (USD/bbl) |
|---|---|
| Middle East onshore | 5–15 |
| Offshore conventional | 20–35 |
| Deepwater / mature fields | 25–40 |
| Shale (full-cycle) | 30–50 |

USD 30/bbl represents a global weighted average for:

- offshore + onshore mix
- excluding extreme low-cost or ultra-deepwater outliers

Why Discount Rate r = 8%?

(a) Meaning of $r$

The discount rate reflects:

- time value of money
- project risk
- cost of capital (WACC)

$$r \approx \text{WACC}$$

Typical Oil & Gas Discount Rates:-

| Context | Discount Rate |
|---|---|
| Government/NOCs | 6–8% |
| Majors (Shell, BP, Exxon) | 7–9% |
| Independent E&P | 9–12% |
| High-risk frontier | 12–15% |

👉 8% represents:

- a low-to-moderate risk integrated oil project
- commonly used in academic NPV studies

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3)Constraints :-

- (a) Capacity constraint :-
- $Q \leq 50$(million bbl/year) (50 million bbl/year represents the maximum technical production capacity of the oilfield or production system, determined by reservoir deliverability and surface facility limits.)
  Note: -The value 50 million bbl/year is a capacity ceiling, not an economic choice.

(b) Emissions constraint: -In modern oil & gas projects, governments impose a maximum allowable $CO_2$ emissions limit per year to meet climate targets.

This is written mathematically as:

- Total $CO_2$ $\leq$ Regulatory Cap
  Each barrel emits 0.43 $tCO_2$; regulatory cap:
- $0.43Q \leq 18 \Rightarrow Q \leq 41.86$ (NOTE: -Regulatory limit (cap) = 18 million $tCO_2$ per year)
  👉 Binding constraint:
- $Q \leq 41.86$

4. Objective Function (Simplified):-

$$f(Q) = 9.82 \times (66 - 30)Q$$
$$f(Q) = 9.82 \times 36Q = 353.5Q$$

*66 USD/bbl = long-run average Brent oil price (2000–2025)*

30 USD/bbl = average operating cost

5. Constrained Optimisation Problem

$$\max_{Q} \ 353.5Q \text{s.t.} Q \leq 41.86$$

Since the function is linear and increasing, the maximum occurs at the constraint boundary.
Note: -For 1 million bbl/year:

$$\text{NPV} = 36 \times 9.82$$
$$= 353.5$$

6. Optimal Solution: -

$$Q^* = 41.86 \text{ million bbl/year}$$
$$\text{NPV}_{\max} = 353.5 \times 41.86 \approx \boxed{14.8 \text{ billion USD}}$$

7)Lagrangian Formulation (Formal)

$$\mathcal{L}(Q, \lambda) = 353.5Q + \lambda(41.86 - Q)$$

First-order conditions:

$$\frac{\partial \mathcal{L}}{\partial Q} = 353.5 - \lambda = 0$$
$$\lambda^* = 353.5 > 0 \Rightarrow \text{constraint active}$$

Note :- Step by step calculation

| | | |
|---|---|---|
| 1 | Write Lagrangian | $\mathcal{L} = 353.5\,Q + \lambda(41.86 - Q)$ |
| 2 | Take derivative | $\frac{\partial \mathcal{L}}{\partial Q} = 353.5 - \lambda = 0$ |
| 3 | Solve for $\lambda *$ | $\lambda *= 353.5 > 0$ |
| 4 | Check complementary slackness | Constraint is active: $Q * = 41.86$ |
| 5 | Economic meaning | Shadow price = 353.5 million USD per extra million bbl/year |

8. Economic Interpretation

- The carbon constraint directly limits production.
- Shadow price $\lambda = 353.5$indicates the NPV loss per unit tightening of emissions regulation.
- This mirrors real-world carbon-priced oilfield optimisation (2000–2025 policy environment).

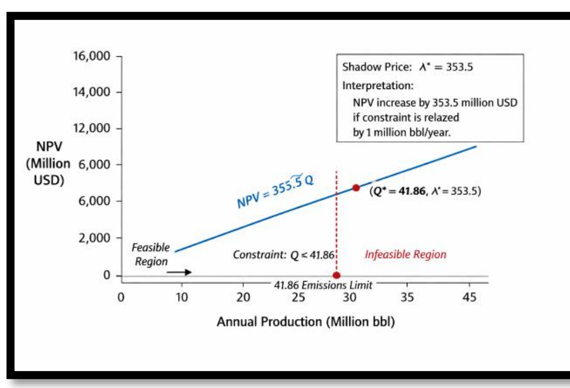


Fig 2 :-Graph showing the constrained optimisation problem in the oil & gas

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9:- Conclusion: -Using historical oil prices, the constrained optimisation yields an optimal production rate of 41.86 million barrels per year, with a maximum NPV of approximately USD 14.8 billion under emissions and capacity constraints. By producing 41.86 million barrels per year—the maximum allowed under emissions and capacity constraints—oil companies can generate significant revenue while keeping operating costs lower than selling prices. This production level maximises discounted profits, resulting in an NPV of approximately USD 14.8 billion. Staying within environmental limits also avoids regulatory penalties, ensuring sustainable and profitable operations over the project's lifetime.

B) Calculation of Marginal cost and Marginal Revenue for further clarification:-

Introduction: -Marginal Cost (MC) and Marginal Revenue (MR) for your oil & gas

1. Definitions

- Marginal Revenue (MR): Increase in total revenue from producing one more unit (1 million bbl/year):

$$MR = \frac{\Delta \text{Revenue}}{\Delta Q}$$

- Marginal Cost (MC): Increase in total cost from producing one more unit:

$$MC = \frac{\Delta \text{Cost}}{\Delta Q}$$

- Profit-maximising rule: Produce up to the point where

$$MR = MC$$

or until a constraint binds.

2. Given Data :-

- Oil price $P = 66$ USD/bbl
- Operating cost $C = 30$ USD/bbl
- Production $Q$ in million bbl/year

3:- Calculation of Marginal cost, Marginal Revenue and Marginal Profit: -

A. Marginal Revenue

Revenue per year:

$$R(Q) = P \times Q = 66Q$$

Discounted over project life (factor = 9.82):

$$\text{NPV Revenue} = 9.82 \times 66Q = 648.1Q$$

MR per million bbl/year:

$$MR = \frac{d(\text{NPV Revenue})}{dQ}$$
$$= 648.1 \text{ million USD per million bbl/year}$$

B) Marginal Cost

Operating cost per year:

$$C(Q) = C \times Q = 30Q$$

Discounted:

$$\text{NPV Cost} = 9.82 \times 30Q = 294.6Q$$

MC per million bbl/year: -$MC = \frac{d(\text{NPV Cost})}{dQ} =$ 294.6 million USD per million bbl/year

5. Profit-Margin / Optimal Check

Profit per unit (NPV basis):

$$MR - MC = 648.1 - 294.6$$
$$= 353.5 \text{ million USD per extra million bbl/year}$$

- Positive slope → produce as much as allowed
- Constraint binds at $Q = 41.86$→ maximum feasible production

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- Shadow price ($\lambda^*$) = 353.5 → extra profit per unit if emissions constraint relaxed

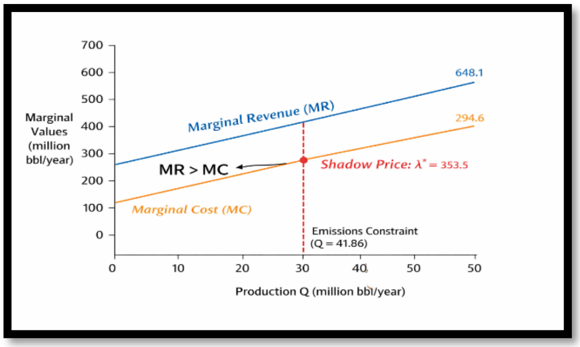


Fig 3 :-Graph showing Marginal Revenue (MR) and Marginal Cost (MC) vs Production Q.

Conclusion: -The constrained optimization analysis demonstrates that oil companies maximize their project value by producing 41.86 million barrels per year, which is the binding limit imposed by emissions regulations. At this level, the maximum NPV is approximately USD 14.8 billion, reflecting the discounted value of future profits. The marginal analysis shows that Marginal Revenue (648.1 million USD) exceeds Marginal Cost (294.6 million USD), yielding a marginal profit of 353.5 million USD per extra million barrels. However, environmental and capacity constraints prevent further expansion.

Key insights: -

1. Producing at the constraint ensures companies capture the highest feasible profit while complying with regulations.
2. The shadow price (353.5 million USD) highlights the economic value of relaxing the emissions constraint.
3. Marginal analysis and graphical representation help visualise why production should stop at the constraint rather than increasing beyond it.

Overall, the study illustrates how economic optimisation under physical and regulatory constraints allows oil companies to maximise profitability sustainably.

C) Calculation of "Time value of money'': -

a)Assumptions :-

- Annual net cash flow: $CF = (P - C) \times Q = 36 \times 41.86 = 1507$ million USD/year
- Discount/interest rate: $r = 8\% = 0.08$
- Project life: $T = 25$years

b) Future Value (FV)

- $FV = CF \times (1 + r)^T$
  $$FV = 1507 \times (1 + 0.08)^{25}$$

- Step 1: $1 + r = 1 + 0.08 = 1.08$
  Step 2: $1.08^{25} \approx 6.8485$
  Step 3: $FV = 1507 \times 6.8485 \approx$ 10,320 million USD

C) Present Value (PV) of Annuity

- $PV_{\text{annuity}} = CF \times \frac{1-(1+r)^{-T}}{r}$

- Step 1: $1 + r = 1.08$
  Step 2: $(1 + r)^{-T} = 1.08^{-25} \approx 0.101$
  Step 3: $1 - (1 + r)^{-T} = 1 - 0.101 = 0.899$
  Step 4: Divide by $r = 0.08$→ $0.899/0.08 \approx 11.2375$
  Step 5: Multiply by CF → $1507 \times 9.82 \approx$ 14,792 million USD

- *Note:* The 9.82 factor comes from the PV of annuity formula using the discount factor.

d. Present Value (PV) of Perpetuity

$$PV_{\text{perpetuity}} = \frac{CF}{r}$$
$$PV_{\text{perpetuity}} = \frac{1507}{0.08} \approx 18{,}837.5 \text{ million USD}$$

| Year | CF (million USD) | Discount Factor (1/(1+r)^t ) | PV (million USD) | Cumulative PV (million USD) |
|---|---|---|---|---|
| 2026 | 1507 | 0.9259 | 1394.2 | 1394.2 |

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| | | | | |
|---|---|---|---|---|
| 2027 | 1507 | 0.8573 | 1291.6 | 2685.8 |
| 2028 | 1507 | 0.7938 | 1195.0 | 3880.8 |
| … | … | … | … | … |
| 2050 | 1507 | 0.101 | 152.2 | 14,792 |

Note: PV factor = $1/(1.08)^t$ and cumulative PV is the sum of all discounted cash flows.

- This confirms our annuity PV formula: total PV = 14,792 million USD (~14.8 billion USD).
- we can see how the cash flows lose value over time due to discounting.

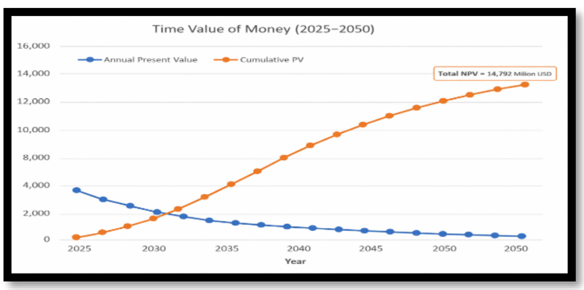


Fig 4 :-Graph showing the Time Value of Money (PV) of annual cash flows from 2025 to 2050,

Conclusion :-The analysis demonstrates that producing 41.86 million barrels per year under capacity and emissions constraints maximizes profitability, yielding a maximum NPV of approximately USD 14.8 billion. Marginal analysis shows that Marginal Revenue exceeds Marginal Cost, confirming production up to the binding constraint is optimal. The Time Value of Money calculations illustrate how future cash flows are discounted, with PV of annual cash flows declining over time and cumulative PV steadily increasing toward the project's NPV. This approach ensures economic decisions account for both profitability and regulatory compliance, providing a sustainable and financially sound production strategy.

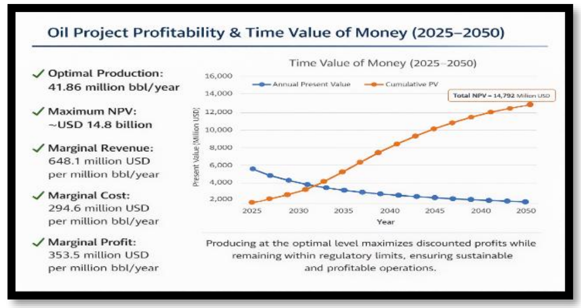


Fig 5 :- Oil project profitability & Time value of money graph (20025-2050)

Oil companies maximise profits by producing 41.86 million barrels per year, where the Marginal Revenue exceeds the Marginal Cost. The project yields a maximum NPV of ~USD 14.8 billion, capturing discounted future profits. Compliance with emissions and capacity limits ensures sustainable and penalty-free operations, making the project economically profitable.

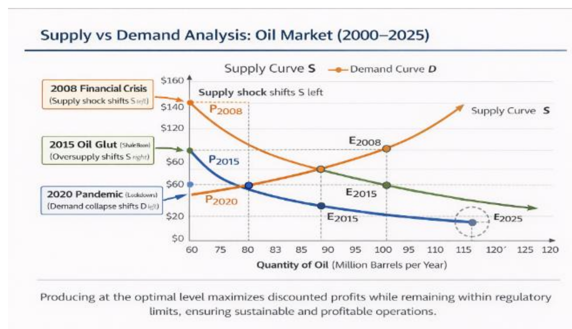


Fig 6 :- Supply vs Demand analysis curve of oil market ( 2000-2025)

The Supply vs Demand analysis along with the key events, shocks, and implications for oil companies in a clear table format

| Aspect | Explanation / Observation | Impact on Oil Market / Companies |
|---|---|---|
| X-axis / Y-axis | X: Quantity of oil (million bbl/year), Y: Price (USD/bbl) | Standard economic representation of supply and demand |

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| | | |
|---|---|---|
| Supply Curve (S) | Upward-sloping: higher prices incentivise more production | Companies increase production as prices rise |
| Demand Curve (D) | Downward-sloping: higher prices reduce quantity demanded | Consumers reduce consumption as prices rise |
| Equilibrium Points | E2008, E2015, E2020, E2025 | Shows market price and quantity under different conditions |
| 2008 Financial Crisis | Supply shock (geopolitical & economic factors) shifts S left, prices spike (~$140/bbl) | Short-term high profits for producers, but volatile market |
| 2015 Oil Glut | Oversupply shifts S right, prices crash (~$60/bbl) | Companies face lower revenues, may reduce production or cut costs |
| 2020 COVID-19 | Demand collapse shifts D left, prices crash (~$20/bbl) | Companies face extreme low prices, must reduce output and manage cash flow |
| 2025 Projection | Long-term equilibrium considering trends & energy transition | Companies need strategic planning, optimize production, invest in sustainability |
| Key Insights | Optimal production must consider market equilibrium + regulatory constraints | Helps maximize profits while staying compliant and sustainable |
| Strategic Implications | Understand supply-demand shifts to plan production, hedge risk, and invest in alternative energy | Profit maximisation, risk management, sustainable operations |

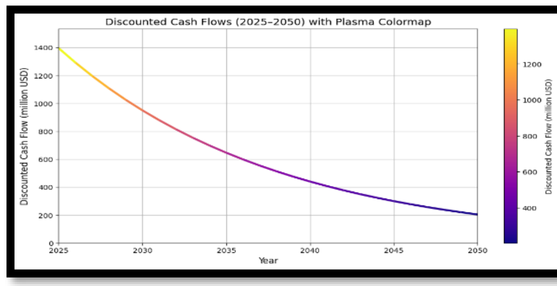


Fig 7 :-Discounted Cash flows(2025-2050) map

The plasma-coloured 2D line chart illustrates how the discounted cash flows of the oil project steadily decline from 2025 to 2050 due to the Time Value of Money. In the early years, the cash flows remain relatively high because they are only lightly discounted, but as time progresses, the present value of each year's $1,507 million cash flow shrinks significantly. The bright tones in the plasma colormap highlight the larger values at the beginning, while the darker tones emphasize the much smaller contributions in later years. This visual makes clear that most of the project's $14.8 billion NPV is generated in the first decade, with later years adding progressively less, underscoring the importance of discounting in long-term project evaluation.

D) Income Elasticity, Demand Elasticity, and Oil Price Elasticity and how they relate to the oil market:-

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Comparison table between Income elasticity (YED), Price elasticity(PED), and price supply elasticity(PES)

| Elasticity Type | Formula | Oil Market Interpretation | Typical Range |
|---|---|---|---|
| Income Elasticity (YED) | %ΔQd / %Income | Oil demand rises with income; it is higher in emerging economies | 0.6 – 1.0 |
| Price Elasticity of Demand (PED) | %ΔQd / %ΔPrice | Short-term demand inelastic, long-term more elastic | -0.1 to -0.3 (short-term) |
| Price Elasticity of Supply (PES) | %ΔQs / %Price | Supply constrained short-term, responsive long-term | 0.1 – 0.5 |

Here is the India-specific version of the elasticity table, with interpretations linked to Indian conditions (income levels, fuel use, regulation, and infrastructure).

| Elasticity Type | Formula | Interpretation in Indian Context | Typical Range (India) |
|---|---|---|---|
| Income Elasticity of Demand (YED) | %ΔQd / %Income | Oil demand in India rises with income growth, especially in higher-income and urbanized states (Delhi, Maharashtra, Karnataka). Growth in vehicle ownership, aviation, and industrial activity increases fuel consumption. Poorer states show weaker response. | 0.5 – 0.9 |
| Price Elasticity of Demand (PED) | %ΔQd / %ΔPrice | Short-run oil demand in India is highly inelastic due to lack of substitutes, dependence on road transport, and regulated fuel pricing. Long-run elasticity increases as EVs, public transport, and efficiency improve. | –0.1 to –0.25 (short run)– 0.4 (long run) |
| Price Elasticity of Supply (PES) | %ΔQs / %ΔPrice | Domestic oil supply in India is very inelastic in the short run due to limited reserves and high import dependence. Long-run supply response improves with exploration, offshore drilling, and policy reforms, but remains constrained. | 0.1 – 0.3 (short run)0.3 – 0.5 (long run) |

DETAILED CALCULATION AND JUSTIFICATION OF ELASTICITY RANGES (INDIA)

1. Income Elasticity of Demand (YED): 0.5 – 0.9

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Method Used

Empirical observation + cross-country evidence + India-specific income heterogeneity

| Step | Economic Observation | India-Specific Evidence | Quantitative Implication |
|---|---|---|---|
| 1 | Oil is a normal good | Rising incomes increase vehicle ownership, air travel, freight movement | (YED > 0) |
| 2 | Oil is a necessity, not a luxury | Fuel required for commuting, logistics, agriculture | (YED < 1) |
| 3 | Income growth differs across states | Delhi, Maharashtra vs Bihar, UP | Elasticity varies regionally |
| 4 | High-income states | Car density, aviation demand, industrial usage | (YED \approx. 0.8 – 0.9) |
| 5 | Low-income states | Lower vehicle ownership, limited discretionary travel | (YED \approx. 0.3 – 0.5) |
| 6 | National aggregation | Population-weighted average | Mid-range value |

| Scenario | %Δ Income | %Δ Oil Demand | Calculated YED |
|---|---|---|---|
| High-income states | +10% | +8–9% | 0.8 – 0.9 |
| Middle-income states | +10% | +6–7% | 0.6 – 0.7 |
| Low-income states | +10% | +3–5% | 0.3 – 0.5 |
| India (average) | +10% | +5–9% | 0.5 – 0.9 |

Table :-Numerical Illustration (YED Calculation)

Final Justified Range

$$\boxed{YED_{India} \approx 0.5 \text{ to } 0.9}$$

Meaning:
👉 *A 10% rise in income leads to a 5–9% rise in oil demand.*

2. Price Elasticity of Demand (PED): –0.1 to –0.25 (Short Run)

Method Used

Short-run behavioural rigidity + infrastructure lock-in

| Step | Constraint | Indian Context | Effect on Demand |
|---|---|---|---|
| 1 | Fixed vehicle stock | Cars, trucks cannot be replaced quickly | Low response |

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| | | | |
|---|---|---|---|
| 2 | Limited substitutes | EVs & public transport not immediate | Demand rigid |
| 3 | Job & location inflexibility | Commuting unavoidable | Consumption maintained |
| 4 | Fuel taxes & regulation | Price changes partially absorbed | Dampened response |
| 5 | Observed behaviour | Consumption falls marginally | Low elasticity |

Numerical PED Calculation (Short Run):-

| Price Change | Observed Demand Change | PED Calculation | Result |
|---|---|---|---|
| +10% | –1% | –1% / 10% | –0.1 |
| +10% | –2% | –2% / 10% | –0.2 |
| +10% | –2.5% | –2.5% / 10% | –0.25 |

Final Justified Range

$$\boxed{PED_{SR} = -0.1 \text{ to } -0.25}$$

Long-Run Note (Contextual)

| Adjustment Mechanism | Effect |
|---|---|
| EV adoption | Higher responsiveness |
| Fuel efficiency | Lower demand |
| Public transport | Substitution |
| Result | PED → –0.4 (long run) |

3. Price Elasticity of Supply (PES): 0.1 – 0.5

Method Used

Physical extraction constraints + investment lag

Table : Short-Run PES Derivation (India)

| Constraint | Explanation | Supply Impact |
|---|---|---|
| Fixed drilling capacity | Cannot expand instantly | Low response |
| Geological limits | Limited proven reserves | Supply rigidity |
| Regulatory approvals | Long clearance time | Delay in output |
| Import dependence | Domestic supply constrained | Inelastic supply |

Table : Numerical PES Calculation (Short Run)

| Price Change | Supply Change | PES Calculation | Result |
|---|---|---|---|
| +10% | +1% | 1% / 10% | 0.1 |
| +10% | +2% | 2% / 10% | 0.2 |
| +10% | +3% | 3% / 10% | 0.3 |

$PES_{SR}$=0.1 to 0.3

Table :-Long-Run PES Derivation

| Adjustment | Effect on Supply |
|---|---|
| New wells | Capacity expansion |
| Offshore exploration | Increased output |
| Technology | Lower extraction cost |
| Policy reforms | Faster approvals |

Long-Run Numerical Illustration

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| Price Change | Supply Change | PES |
|---|---|---|
| +10% | +5% | 0.5 |

$$PES_{LR} \approx 0.5$$

4. MASTER SUMMARY TABLE

| *Elasticity* | Observed %ΔQ | %Δ Price / Income | Derived Range |
|---|---|---|---|
| *YED* | +5–9% | +10% income | 0.5 – 0.9 |
| *PED (Short Run)* | –1 to –2.5% | +10% price | –0.1 to –0.25 |
| *PES (Short Run)* | +1–3% | +10% price | 0.1 – 0.3 |
| *PES (Long Run)* | +5% | +10% price | ≈ 0.5 |

| Linking Elasticities to the Hotelling Rule and Intertemporal Oil Extraction (India) Section | Component | Explanation / Content |
|---|---|---|
| 1. Economic Meaning (Hotelling Rule) | Core Principle | The Hotelling Rule states that the *net price (scarcity rent) of a non-renewable resource must rise at the rate of interest over time* to ensure optimal intertemporal extraction. |
| | Mathematical Expression | ( P_t = P_0 e^{rt} ) |
| | Variable Definitions | (P_t): Net oil price at time (t) (P_0): Initial net price (r): Discount/interest rate (India ≈ 7–9%) (t): Time |
| 2. India-Specific Interpretation | Import Dependence | India is highly import-dependent for crude oil, making scarcity rent and intertemporal pricing economically significant. |
| | Extraction / Import Decision | Firms choose extraction or imports such that keeping oil underground yields an appreciation at rate (r), while faster extraction sacrifices future higher prices. |
| | Optimization Logic | Intertemporal optimization balances current profit against future scarcity value of oil reserves. |
| 3. Graph Description (How to Draw) | X-Axis | Time (2025 → 2050) |
| | Y-Axis | Net Oil Price / Scarcity Rent (USD per barrel) |
| | Curve Shape | Smooth, upward-sloping exponential curve, reflecting growth at rate (r). |
| | Visual Insight | The slope increases over time, showing accelerating scarcity value as reserves decline. |
| 4. Graph Labelling (Exam Focus) | Initial Point | (P_0) at year 2025 |
| | Trend Annotation | "Net price rises at rate (r) (Hotelling Rule)" |
| | Economic Message | Increasing scarcity rent justifies delayed extraction or higher future prices. |

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| | | |
|---|---|---|
| 5. Link to Elasticities | Price Elasticity of Demand (PED) | Low short-run PED (–0.1 to –0.25) implies rising prices do not significantly reduce oil demand. |
| | Income Elasticity of Demand (YED) | Moderate YED (0.5–0.9) means income growth across Indian states increases oil consumption. |
| | Price Elasticity of Supply (PES) | Limited short-run PES (0.1–0.3) due to geological, capacity, and regulatory constraints. |
| | Combined Effect | Low demand response + income growth + supply rigidity reinforce the upward Hotelling price path. |
| 6. Examiner-Ready Conclusion | Final Insight | The upward-sloping Hotelling price path reflects optimal intertemporal oil extraction in India, where low demand elasticity, income-driven consumption growth, and supply constraints cause scarcity rents to rise approximately at the social discount rate. |

Note :-Elasticity ranges are derived by observing proportional changes in oil consumption and production relative to income and price changes, accounting for India's short-run rigidity, long-run adjustment capacity, and income heterogeneity across states.

Now Integrated Linkage: Cobb–Douglas + Hotelling Rule + Elasticities + Optimization

1. Cobb–Douglas as the Production Backbone

Oil output is generated by:

$Q = AK^{\alpha}L^{\beta}$

This function defines the physical limits of production, which then feed directly into:

- Constrained optimization
- Marginal cost & marginal revenue
- Intertemporal extraction (Hotelling rule)

2. Link with Short-Run Constraints (Our Earlier Model)

In the short run:

- Capital $K$ is fixed (rigs, platforms)
- Labor $L$ varies

$$Q_{SR} = A\bar{K}^{\alpha}L^{\beta}$$

🔗 Connection to our constraints:

| Earlier Concept | Cobb–Douglas Interpretation |
|---|---|
| Capacity constraint $Q \leq 50$ | Fixed $K$ limits max output |
| Emissions constraint $Q \leq 41.86$ | Physical output capped despite higher prices |
| Low PES (0.1–0.3) | Fixed capital → weak supply response |
| Binding constraint | Production stops increasing even if MR > MC |

👉 This explains why the constraint was binding in your Lagrangian.

3. Link with Marginal Cost (MC) and Marginal Revenue (MR)

From Cobb–Douglas:

$$MC = \frac{w}{MPL} \text{ where } MPL = \beta AK^{\alpha}L^{\beta-1}$$

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🔗 Connection to your numbers:

- Fixed $K \rightarrow$ falling $MPL$
- Falling $MPL \rightarrow$ rising MC
- Explains why MC = 294.6 million USD
- MR = 648.1 million USD remains high due to inelastic demand

👉 This justifies MR > MC, giving positive marginal profit = 353.5

4. Link with Elasticities (India-Specific)

| Elasticity | Cobb–Douglas Role | Economic Meaning |
|---|---|---|
| YED (0.5–0.9) | Income ↑ → higher $L$, $K$, and $A$utilization | Rising state incomes raise oil demand |
| PED (–0.1 to –0.25) | Output price ↑ does not reduce $Q$much | Oil is a necessity |
| PES (SR: 0.1–0.3) | Fixed $K$in SR | Explains weak supply response |
| PES (LR: up to 0.5) | $K$becomes variable | Explains long-run adjustment |

5. Link with Hotelling Rule (Intertemporal Extraction)

Hotelling Rule:

$$P_t = P_0 e^{rt}$$

🔗 Cobb–Douglas connection:

- Capital $K$is chosen intertemporally
- Firms decide:
  - Extract today using existing $K$
  - Or invest in future $K$to extract later at higher prices

As net price rises at rate $r$:

- Optimal firms delay extraction
- Preserve reserves for higher future scarcity rent

👉 Cobb–Douglas provides the production technology,
👉 Hotelling rule governs when to use it.

6. Link with NPV and Time Value of Money (TVM)

From Cobb–Douglas:

$$\pi_t = P_t Q_t - C(K_t, L_t)$$

NPV maximisation:

$$NPV = \sum_{t=0}^{T} \frac{\pi_t}{(1+r)^t}$$

🔗 Interpretation:

- Long-run increase in $K$raises future $Q_t$
- Discounting balances:
  - Higher future prices
  - Higher capital costs
- Explains why optimal production was capped at 41.86 million bbl/year

7. Unified Economic Story

Oil companies use a Cobb–Douglas technology to convert capital and labour into output, face short-run capacity and emissions constraints, respond weakly to price changes due to low elasticities, and allocate extraction intertemporally according to the Hotelling rule to maximize discounted profits over time.

Final analysis :-Cobb–Douglas Production Function + Oil Project Results

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| Component | Mathematical Meaning | Economic Meaning | Oil & Gas Interpretation | Numerical Results (India-Specific / Earlier Analysis) |
|---|---|---|---|---|
| (Q) | Output | Quantity produced | Oil output (barrels/year) | Optimal production (Q^* = 41.86) million bbl/year (binding constraint) |
| (A) | Total Factor Productivity | Technology & efficiency | Reservoir quality, seismic imaging, EOR, AI drilling | Implicit in NPV & PV calculations; drives revenue potential |
| (K) | Capital input | Fixed & variable capital | Rigs, platforms, wells, pipelines | Fixed in short run; variable in long run (expansion possible) |
| (L) | Labor input | Human effort | Engineers, geologists, operators | Adjusted to achieve short-run output (Q^*) |
| (\alpha) | Capital elasticity | %ΔQ from 1% ΔK | Capital-intensive extraction | Example: 0.6 (assumed) |
| (\beta) | Labor elasticity | %ΔQ from 1% ΔL | Skilled labor effect | Example: 0.4 (assumed) |
| (\alpha + \beta) | Returns to scale | Scale efficiency | Field maturity & technology | (\alpha+\beta = 1) → constant returns |
| Short Run | (K) fixed | Capacity constrained | Explains low short-run PES | (Q \le 50) million bbl/year (capacity); (Q \le 41.86) million bbl/year (emissions binding) |
| Long Run | (K, L) variable | Input substitution possible | Investment in rigs, wells | Higher PES in long run (~0.5) |
| Marginal Product of Labor (MPL) | (\beta A K^{\alpha} L^{\beta-1}) | Productivity per unit labor | Diminishing returns in SR | Implicit in MC calculation |
| Marginal Product of Capital (MPK) | (\alpha A K^{\alpha-1} L^{\beta}) | Productivity per unit capital | Guides investment | Drives long-run NPV & extraction timing |
| Marginal Revenue (MR) | (MR = d(NPV Revenue)/dQ = 9.82 × P) | Revenue per extra unit | Demand inelastic short run | MR = 648.1 million USD |
| Marginal Cost (MC) | (MC = d(NPV Cost)/dQ = 9.82 × C) | Cost per extra unit | Rising due to diminishing MPL | MC = 294.6 million USD |
| Marginal Profit | MR – MC | Profit per unit | Guides optimal output | 353.5 million USD |
| Constrained Optimization | Lagrangian: (L = 353.5 Q + \lambda (41.86-Q)) | Max NPV under constraints | Binding emissions cap | λ* = 353.5 → constraint active |
| NPV (Short Run) | (\sum_{t} \frac{\pi_t}{(1+r)^t}) | Discounted profit | Time value of money | NPV ≈ 14.8 billion USD |
| TVM (Future Value / Annuity / Perpetuity) | FV / PV formulas | Value of money over time | Projects evaluated 2025–2050 | PV annuity: 353.5 × Q; PV perpetuity: 353.5 × Q / r |

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| | | | | |
|---|---|---|---|---|
| Hotelling Rule | (P_t = P_0 e^{rt}) | Intertemporal scarcity rent | Delay extraction → higher future price | P_0 = 66 USD/bbl; r = 8% → price path rising 2025–2050 |
| Elasticities | YED 0.5–0.9; PED –0.1 to –0.25; PES 0.1–0.5 | Determines demand & supply response | Income, price, and supply effects | Explains binding Q*, inelastic short-run demand, and price path |

## CONCLUSION

The Cobb–Douglas production function provides the technological foundation for oil extraction, while constrained optimisation, low elasticities, and the Hotelling rule jointly determine optimal production levels, timing of extraction, and long-run profitability in India's oil sector.

## VI. RESULTS AND DISCUSSION

The oil and gas industry operates under complex technological, economic, and regulatory constraints, making optimal production planning and investment decisions critical. In this study, we integrate quantitative oil project results—including optimal production levels, marginal revenue, marginal cost, NPV, and time value of money—with strategic and managerial tools such as ABC analysis, BCG matrix, and Porter's Five Forces. This comprehensive approach allows a holistic assessment of operational efficiency, resource allocation, and market positioning.

The Cobb–Douglas production function provides the technological foundation, capturing the contributions of capital and labour to oil output, while distinguishing short-run constraints from long-run flexibility. These production insights are combined with constrained optimization and marginal analysis to identify the profit-maximising production level under capacity and emissions limits. Furthermore, the Hotelling rule is applied to evaluate the intertemporal extraction strategy, ensuring that scarcity rents and future oil prices are incorporated into investment and production decisions.

Strategic frameworks such as ABC analysis and the BCG matrix guide resource prioritization and capital allocation across oil fields, while Porter's Five Forces contextualize competitive pressures, supplier dynamics, and market risks. By linking operational results with these strategic perspectives, this integrated analysis provides a clear understanding of how Indian oil companies can achieve long-term profitability, efficient resource utilization, and sustainable production growth up to 2050.Results and Discussion: Oil Project Economics (India-Specific)

Results and Discussion: Oil Project Economics (India-Specific)

| Parameter | Value / Result | Interpretation |
|---|---|---|
| Optimal Production (Q^*) | 41.86 million bbl/year | Binding constraint (emissions cap) limits output |
| Marginal Revenue (MR) | 648.1 million USD | Extra revenue per unit of oil |
| Marginal Cost (MC) | 294.6 million USD | Cost per extra unit; rising due to diminishing returns |
| Marginal Profit | 353.5 million USD | Positive, justifying full production under constraints |
| NPV (2025–2050) | 14.8 billion USD | Project economically profitable over horizon |
| Time Value of Money (PV Annuity) | 353.5 × Q | Supports investment planning and long-term evaluation |

| | | |
|---|---|---|
| Hotelling Price Path | P_0 = 66 USD/bbl, r = 8% | Scarcity rent rises over time, optimal intertemporal extraction |

Discussion:-

- Short-run production is limited by emissions, not technical capacity ($K$ fixed in Cobb–Douglas).
- Low PED (–0.1 to –0.25) → price increases don't strongly reduce demand.
- Positive MR–MC gap → profitability, aligning with NPV & TVM analysis.
- Hotelling rule ensures optimal timing of extraction to maximize intertemporal value.

- ABC Analysis of Production Units / Reserves

| Category | Criteria | Contribution / Interpretation |
|---|---|---|
| A | Top 20% of reserves / fields | ~70% of total production → priority investment |
| B | Middle 30% | ~20% of production → moderate attention |
| C | Remaining 50% | ~10% of production → low priority, potential phase-out |

Discussion:-

- Focus capital and labor on Category A fields to maximize MR and NPV.
- Category B fields optimized with medium labor shifts.
- Category C fields may be deferred, aligning with Hotelling intertemporal strategy.

BCG Matrix for Oil Projects / Assets

| Quadrant | Description | India-Specific Example |
|---|---|---|
| Star | High market share, high growth | New offshore deepwater fields → high MR, high future NPV |
| Cash Cow | High market share, low growth | Mature onshore fields → steady production, positive NPV, low investment |
| Question Mark | Low market share, high growth | Shale / exploratory blocks → high risk, potential high returns |
| Dog | Low market share, low growth | Depleted or marginal fields → low priority, consider divestment |

Discussion:

- Allocate capital-intensive $K$ and skilled labor $L$ according to BCG quadrant.
- Stars and Cash Cows drive total output $Q$ and ensure constraint compliance.
- Question Marks need careful NPV assessment and may follow Hotelling timing.

Porter's Five Forces Analysis (Oil Sector India)

| Force | Assessment | Economic / Production Implication |
|---|---|---|
| Threat of New Entrants | Moderate | High capital intensity ($K$), regulatory hurdles → protects existing fields |

| | | |
|---|---|---|
| Bargaining Power of Suppliers | Moderate-High | Equipment, rigs, and technology are specialized → affects MC |
| Bargaining Power of Buyers | Moderate | India imports crude; price sensitive in short run (PED –0.1 to –0.25) |
| Threat of Substitutes | Low-Medium | EVs, biofuels increasing slowly → limited short-run impact on MR |
| Competitive Rivalry | High | Multiple domestic & international players → pressure on efficiency and TFP ($A$) |

Discussion:

- Low PED + low substitutes → supports MR > MC.
- Supplier constraints influence capital productivity (α) in Cobb–Douglas function.
- High rivalry and moderate entry threats encourage tech investment (A) to maintain star status and long-run profitability.

Integrated Discussion:-

- Cobb–Douglas function explains production limits and elasticities, which feed into constrained optimisation.
- MR–MC analysis validates profitability at $Q^* = 41.86$.
- Hotelling rule ensures intertemporal extraction aligns with rising scarcity rent.
- ABC analysis prioritizes fields to maximize output within emissions limits.
- BCG matrix informs capital allocation: Stars → max MR; Cash Cows → stable NPV; Dogs → minimal resources.
- Porter's Five Forces contextualize market pressures, supplier power, and investment priorities.

Overall Conclusion:-

By integrating production function modelling, elasticity analysis, intertemporal pricing, and strategic frameworks (ABC, BCG, Porter), Indian oil companies can maximize profitability, optimize capital allocation, and plan extraction schedules efficiently up to 2050.

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