Analysing Investment Alternatives for Oil Companies using AHP-GP Programming

Introduction

According to an article by Economist, "big oil's coffers are overflowing after two years of sky-high energy prices" (Kilbride, 2023). Profits will be distributed among shareholders, debt repayment and reinvestment. During previous times with high oil prices, oil companies are known to have spent recklessly with too much investment and lack of cost control leading to waste and overproduction. This situation has led to investors demanding greater discipline in capital expenditure. The current policy and social environment are hostile to oil companies due to pandemic-induced demand destruction and climate-related fiascos. Climate change has dealt a blow resulting in repressed investments in oil. Oil companies have grown more risk-averse by retreating from areas with higher political risk. Companies looking to reinvest in a more innovative and green manner while still reaping profits. To fulfil these demands, it is imperative to maximise profits while investing judiciously.

This report aims to forecast a profitable investment model for a fictional oil company, Capybarrel Oil Co. Capybarrel Oil Co. has been loosely modelled using figures from Shell's progress report to make it as realistic as possible. The article in the Economist has been used to simulate an outline of viable investment alternatives.

Model explanation

Two multicriteria techniques – Analytical Hierarchy Programming (AHP) and Goal Programming (GP) was applied to this report, by using the weights in the AHP model and incorporating them into a weighted objective function.

Analytical Hierarchy Programming

To address multicriteria decision problems, AHP was deployed by rating the relative importance of each criterion and then specifying the preference of each decision alternative on the basis of the criterions (Anderson *et al.*, 2017). Table 1 lists the decision alternatives. Criterions are illustrated in Figure 1. The decision-making process is shown in Figure 2.

Table 1: Decision Alternatives

Decision Alternatives (Scenario)	**Description**
D1	Sell manufactured products
D2	Investing in green projects
D3	Restarting trade
D4	Short-Cycle investment

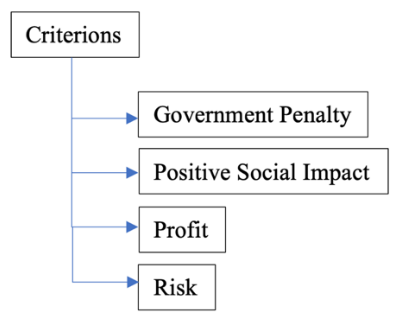

Figure 1: Criterions

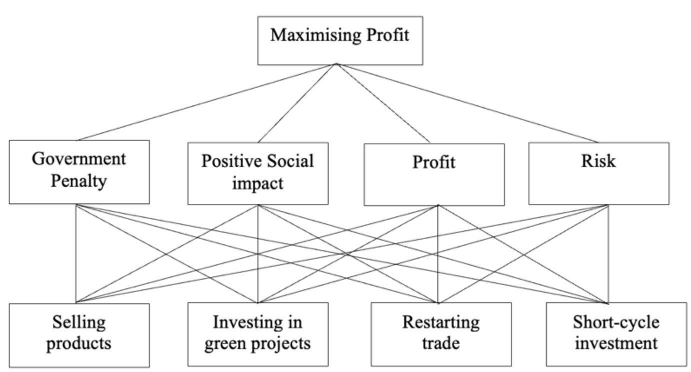

Figure 2: Hierarchy of Decision Alternatives

Numerical ratings were assigned for the pairwise comparison of the criterions. The scale of comparison can be found in Appendix I along with the pairwise matrices in Appendix II.
As per the functional relevance of Capybarrel Oil Co., the following logic was followed for rating:

- Government penalties were deemed “strongly important” over social impact. As an oil company based on capitalist principles, social impact is a lower priority, and exercise wariness of government sanctions and minimise penalties.
- Profit maximisation is the end goal; Profit has been deemed to be “Very strongly more important” over government penalties and it is considered “extremely more important” than social impact.
- Risk and government penalties share a similar importance and are to be avoided.

Subsequently, through synthesisation the priority of each criterion is determined in terms of its overall contribution towards the goal of profit maximisation.

Goal Programming

Goal Programming, a widely used decision making approach first introduced by Charles et al. (1955), is a programming model which has multiple objectives. This model attempts to achieve the goals introduced by a decision-maker as closely as possible, as opposed to following a well-defined utility function (Sahebi, Nickel and Ashayeri, 2015). As solving the problem involves multiple criteria, goal programming will be used as the technique to identify the best course of action that Capybarrel Oil Co. must take when considering where to invest £45 billion.

Objective function:

$$\text{Min } w_1P_1(d_1^-) + w_2P_2(d_2^-) + w_3P_3(d_3^-) + w_4P_4(d_4^-)$$

Hard constraint:

$x_1 + x_2 + x_3 + x_4 \leq 45$ where x_i is the money invested in scenario *i*

Goal equations:

$$ROI_1\, x_1 = Profit_1 + d_1^+ - d_1^-$$
$$ROI_2\, x_2 - \text{risk} + \text{positive social impact} = Profit_2 + d_2^+ - d_2^-$$
$$ROI_3\, x_3 = Profit_3 - \text{government penalty} + d_3^+ - d_3^-$$
$$ROI_4\, x_4 = Profit_4 + d_4^+ - d_4^-$$

Where:

w_i	=	the weight modes for scenario *i* from AHP
P_i	=	the priority level goal for scenario *i*
x_i	=	the money invested in scenario *i*
d_i^+	=	the positive deviation variable of scenario *i*
d_i^-	=	the negative deviation variable of scenario *i*

Figure 3: The Goal Equations

Figure 3 portrays the goal equations. The second scenario includes a risk that comes with adopting the project, equalling to 15% of investment value of scenario 2, as well as a social impact which is 5% of the investment, while the third scenario involves a penalty imposed by the government which accounts for 25% of the profits achieved in scenario 3.

For the purpose of developing an appropriate model for this scenario, numbers are assigned for the return on investment for each case based on the values in Shell (2022) as follows: $ROI_1 = 30\%$, $ROI_2 = 70\%, ROI_3 = 20\%,\ ROI_4 = 24\%$. The next step was assigning profits for each of the scenarios as follows: =£3 billion, Profit 2= £3.2 billion, Profit 3= £4.1 billion, Profit 4= £4.7 billion.

After imputing the allocated values, the model equations used for the prototype demo are illustrated in Figure 4 and Appendix IV.

Goal equations:

$$0.3\ x_1 = 3 + d_1^+ - d_1^-$$
$$0.8\ x_2 - 0.15\ x_2 + 0.05\ x_2 = 3.2 + d_2^+ - d_2^-$$
$$0.2\ x_3 = 4.1 - 0.25 \times 4.1 + d_3^+ - d_3^-$$
$$0.44\ x_4 - 0.2\ x_4 = 4.7 + d_4^+ - d_4^-$$

Figure 4: The Prototype Demo

Analysis

Consistency analysis

Consistency analysis, a fundamental technique for evaluating the reliability of priorities provided by decision-makers in the pairwise comparison matrix, is essential to avoid deceptive solutions (Liu, 2009). To measure the consistency of the matrix, Saaty (1977) proposed the consistency ratio (CR) and provided CR<0.1 as an acceptable threshold.

In the context of Capybarrel's problem, consistency ratios of 0.093, 0.083, 0.076, 0.089 and 0.086 were obtained for the overall goal and pairwise matrix, which compared the relative importance of each decision alternative with respect to the government penalty, the positive social impacts of green products, the company's profit, and risks, respectively. Since all the ratios are less than 0.1, the degree of consistency in the pairwise comparisons are regarded as acceptable, indicating that the matrix used in the decision-making process is reliable and can be used for further analysis.

Result analysis

Decisions regarding project investments are crucial to a company's success and must be carefully considered to maximise returns. In this scenario, four investment options were evaluated: sell manufactured products, investing in green projects, restarting trade and short-cycle investment. After executing the optimisation model, it is evident that £5.47 billion should be invested in selling the products, £4.57 billion in investing green projects, £15.38 billion in restarting trade, and £19.58 billion in short-cycle investment. These investment amounts satisfy the given constraints while minimise the underachievement of each goal.

It is worth noting that selling the products has a negative deviation of 1.36, which means that this project carries more risk than the others. However, the other constraint-related factors must also be considered prior to making a final decision.

Sensitivity analysis

According to Saltelli et al. (2008), sensitivity analysis is a means of systematically adjusting the input parameters of a model to determine how variations in these parameters affect the model's results. This is an essential step in ensuring the reliability of models. By conducting sensitivity analysis, decision-makers can gain insight into the relationship between model parameters and outputs, enabling them to identify the most effective and reliable solutions.

In this study one-way sensitivity analysis, which entails varying one parameter at a time while maintaining the others constant, was conducted. The methodology of Tirkolaee et al.'s (2020) study was employed, particularly, the most sensitive parameter was varied between increasing and decreasing by 20% to determine its effect on the objective value. By analysing the sensitivity report (see Appendix III), the d_1^- parameter was identified as the most sensitive. Figure 5 presents that the objective value and the d_1^- parameter are correlated. A 20% rise in d_1^- increased the objective value from 0.23 to 0.28, whereas a 20% drop brought the objective value decreased to 0.19. Overall, underachievement of profits in selling manufacturing products has a central role in determining that objective value, and this fact must be comprehensively examined when making final decisions.

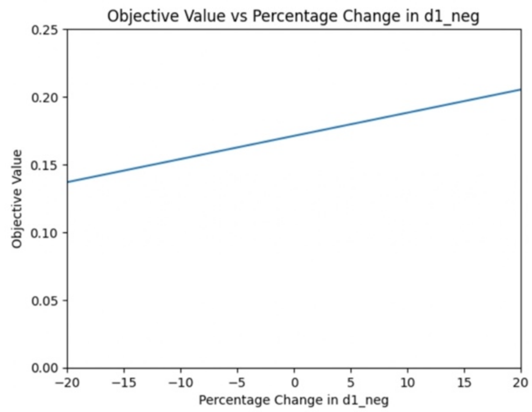

Figure 3: The Sensitivity Analysis of d_1^-

Managerial recommendation

Based on the result of the model and sensitivity analysis, recommendations are provided. Despite its high risk, the best option for the company is investing in selling products which is the core business of a company in oil and gas industry. According to Connell and Hergesheimer (2014), a company must invest in and strengthen its core business to create long-term business profitability and remain competitive in the market. It is recommended that Capybarrel consider diving their investment regarding manufactured products selling into two streams. Firstly, it should establish effective maintenance procedures in production processes that address all potential limitations to improve product quality thereby increasing sales and profitability (Maleti et al., 2012). Secondly, the company should conduct market research, which could result in the company modifying its pricing strategies to gain a competitive advantage on the market (Toni et al., 2017).

In addition, considering the higher risk associated with selling the manufactured products, Capybarrel may benefit from exploring alternative options with lower risk, such as investing in green projects. This approach aligns with the rapid growing focus on environment issues among investors, as highlighted in Defining and Measuring Green Investment (2012).

Limitations

There has been a loss of interest in goal programming due to prior determination of goals being complicated or arbitrary (Zeleny, 1981). AHP acts as a preventative measure. But there are concerns that setting the goals before policy outputs could result in low goals being set. This would further lead to a suboptimal solution. Instead, desirable levels of goals should be policy outputs instead of inputs. This can be prevented by possibly introducing machine learning or multiple iterations over the proposed AHP-GP model.

AHP is subjective to the management's priorities. The model used in this project has been built using simulated information and needs tailoring to fit management's concerns. Elimination of impractical alternatives have not been carried out to allow customization, but this has resulted in possible inaccuracies (Russo and Camanho, 2015). The management may also find it difficult to order the alternatives accurately. Priority ordering can be a conflict-filled process. The Delphi method could be used to combat this issue by helping management decide on a consensus (Khorramshahgol and Al-Husain, 2021).

The values for possible profits have been provided as arbitrary values according to imagined profits for each outcome. This is due to lack of available data. The profit values can be forecasted using historical data which would lead to more accurate decision making.

Conclusion

In conclusion, the report utilised two multicriteria techniques, AHP and GP, to make informed decisions for Capybarrel Oil Co. AHP provided a relative rating of the decision alternatives based on their importance, while GP was used to optimize the investment decisions. This decision support system can guide future decision-making and enhance oil company's investment efficiency. Effective maintenance procedures and market research can further improve pricing strategies, and profitability.

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Appendix I

Comparison scale for the importance of criteria using AHP

Verbal Judgement	Numerical Rating
Extremely more important	9-8
Very strongly more important	7-6
Strongly more important	5-4
Moderately more important	3-2
Equally important	1

Appendix II

CR of each pairwise comparison matrix

	GP	SI	PF	R	Priority	CR
GP	0.082	0.190	0.104	0.059	0.109	
SI	0.020	0.048	0.081	0.024	0.043	
PF	0.574	0.429	0.725	0.824	0.638	
R	0.164	0.238	0.104	0.118	0.156	
						0.093

	d1	d2	d3	d4	Priority	
d1	0.082	0.238	0.121	0.024	0.116	
d2	0.016	0.048	0.081	0.015	0.040	
d3	0.492	0.429	0.725	0.235	0.470	
d4	0.410	0.381	0.363	0.118	0.318	
						0.083

	d1	d2	d3	d4	Priority	
d1	0.082	0.007	3.626	0.235	0.987	
d2	0.574	0.048	5.801	1.059	1.870	
d3	0.016	0.006	0.725	0.059	0.202	
d4	0.041	0.005	1.450	0.118	0.404	
						0.076

	d1	d2	d3	d4	Priority	
d1	0.082	0.333	0.242	0.020	0.169	
d2	0.012	0.048	0.081	0.013	0.038	
d3	0.246	0.429	0.725	0.059	0.365	
d4	0.492	0.429	1.450	0.118	0.622	
						0.089

	d1	d2	d3	d4	Priority	
d1	0.082	0.010	0.104	0.015	0.052	
d2	0.410	0.048	0.145	0.020	0.156	
d3	0.574	0.238	0.725	0.118	0.414	
d4	0.656	0.286	0.725	0.118	0.446	
						0.086

Appendix III

Sensitivity report

```
GLPK 4.65 - SENSITIVITY ANALYSIS REPORT                                                         Page   1

Problem:
Objective:  Objective = 0.2323767857 (MINimum)

   No. Row name     St      Activity         Slack   Lower bound       Activity      Obj coef  Obj value at Limiting
                                          Marginal   Upper bound          range         range   break point variable
------ ------------ -- ------------- ------------- -------------  ------------- ------------- ------------- ------------
     1 C1           NU      45.00000        .               -Inf       39.52976          -Inf        .51300 X1
                                          -.05130       45.00000       49.52976        .05130          .    d1_neg

     2 C2           NS       3.00000        .            3.00000        1.64107          -Inf          .    d1_neg
                                           .17100        3.00000           +Inf          +Inf          +Inf

     3 C3           NS       3.20000        .            3.20000         .02917          -Inf          .    d1_neg
                                           .07329        3.20000        7.02917          +Inf        .51300 X1

     4 C4           NS       3.07500        .            3.07500        2.16905          -Inf          .    d1_neg
                                           .25650        3.07500        4.16905          +Inf        .51300 X1

     5 C5           NS       4.70000        .            4.70000        3.61286          -Inf          .    d1_neg
                                           .21375        4.70000        6.01286          +Inf        .51300 X1
```

```
GLPK 4.65 - SENSITIVITY ANALYSIS REPORT                                                         Page   2

Problem:
Objective:  Objective = 0.2323767857 (MINimum)

   No. Column name  St      Activity      Obj coef   Lower bound       Activity      Obj coef  Obj value at Limiting
                                          Marginal   Upper bound          range         range   break point variable
------ ------------ -- ------------- ------------- -------------  ------------- ------------- ------------- ------------
     1 d1_neg       BS       1.35893        .17100        .             3.00000         .             .     d4_pos
                                           .               +Inf        -3.25357        .23800        .32343 d3_neg

     2 d2_neg       NL        .             .13300        .            -3.82917        .07329        .00372 X1
                                           .05971          +Inf         3.17083          +Inf        .42172 d1_neg

     3 d3_neg       NL        .             .35700        .            -1.09405        .25650        .12243 X1
                                           .10050          +Inf          .90595          +Inf        .32343 d1_neg

     4 d4_neg       NL        .             .51800        .            -1.31286        .21375       -.16706 X1
                                           .30425          +Inf         1.08714          +Inf        .56314 d1_neg

     5 X1           BS       5.47024        .             .            10.00000       -.02010        .12243 d3_neg
                                           .           45.00000       -24.15476        .05130        .51300 d3_pos

     6 X2           BS       4.57143        .             .            10.04167       -.05130       -.00214 d2_pos
                                           .           45.00000          .04167        .04180        .42346 d2_neg

     7 X3           BS      15.37500        .             .            20.84524       -.05130       -.55636 d3_pos
                                           .           45.00000        10.84524        .02010        .54141 d3_neg

     8 X4           BS      19.58333        .             .            25.05357       -.05130       -.77225 d4_pos
                                           .           45.00000        15.05357        .07302       1.66235 d4_neg

     9 d1_pos       NL        .             .             .            -1.35893       -.17100          .    d1_neg
                                           .17100          +Inf            +Inf          +Inf          +Inf

    10 d2_pos       NL        .             .             .            -3.17083       -.07329          .    d1_neg
                                           .07329          +Inf         3.82917          +Inf        .51300 X1
```

```
GLPK 4.65 - SENSITIVITY ANALYSIS REPORT                                                         Page   3

Problem:
Objective:  Objective = 0.2323767857 (MINimum)

   No. Column name  St      Activity      Obj coef   Lower bound       Activity      Obj coef  Obj value at Limiting
                                          Marginal   Upper bound          range         range   break point variable
------ ------------ -- ------------- ------------- -------------  ------------- ------------- ------------- ------------
    11 d3_pos       NL        .             .             .             -.90595       -.25650          .    d1_neg
                                           .25650          +Inf         1.09405          +Inf        .51300 X1

    12 d4_pos       NL        .             .             .            -1.08714       -.21375          .    d1_neg
                                           .21375          +Inf         1.31286          +Inf        .51300 X1

End of report
```

Appendix IV

Coding

```
!pip install pulp
import pulp
from pulp import GLPK
!apt-get install -y -qq glpk-utils

prob = pulp.LpProblem("capybarrel_oil_co", pulp.LpMinimize)

X1 = pulp.LpVariable("Manufacturing product selling", lowBound=0, upBound=45, cat='Continuous')
X2 = pulp.LpVariable("New project investment", lowBound=0, upBound=45, cat='Continuous')
X3 = pulp.LpVariable("Trade restarting", lowBound=0, upBound=45, cat='Continuous')
X4 = pulp.LpVariable("Short-cycle investment", lowBound=0, upBound=45, cat='Continuous')
d1_pos = pulp.LpVariable("d1_pos", lowBound=0, upBound=None, cat='Continuous')
d1_neg = pulp.LpVariable("d1_neg", lowBound=0, upBound=None, cat='Continuous')
d2_pos = pulp.LpVariable("d2_pos", lowBound=0, upBound=None, cat='Continuous')
d2_neg = pulp.LpVariable("d2_neg", lowBound=0, upBound=None, cat='Continuous')
d3_pos = pulp.LpVariable("d3_pos", lowBound=0, upBound=None, cat='Continuous')
d3_neg = pulp.LpVariable("d3_neg", lowBound=0, upBound=None, cat='Continuous')
d4_pos = pulp.LpVariable("d4_pos", lowBound=0, upBound=None, cat='Continuous')
d4_neg = pulp.LpVariable("d4_neg", lowBound=0, upBound=None, cat='Continuous')
w1 = 0.171
w2 = 0.133
w3 = 0.357
w4 = 0.518
Profit1 = 3
Profit2 = 3.2
Profit3 = 4.1
Profit4 = 4.7

prob += w1*d1_neg + w2*d2_neg + w3*d3_neg + w4*d4_neg, "Objective"

prob += X1 + X2 + X3 + X4 <= 45, "Profit from last year"
prob += 0.3*X1 - d1_pos + d1_neg == Profit1, "Selling manufactued products"
prob += 0.8*X2 - 0.15*X2 + 0.05*X2 - d2_pos + d2_neg == Profit2, "Green impact"
prob += 0.2*X3 - d3_pos + d3_neg == Profit3 - 0.25*Profit3, "Government penalties"
prob += 0.44*X4 - 0.2*X4 - d4_pos + d4_neg == Profit4, "Risk"

prob.writeLP("capybarrel_oil_co.lp")
prob.solve(GLPK(msg=True, options=['--ranges', 'sensitivity_test.txt']))

print("Model Status: {}".format(pulp.LpStatus[prob.status]))

print("Optimal Solution:")
print("Objective value: ${}".format(round(pulp.value(prob.objective), 2)))
print("X1: {}".format(round(pulp.value(X1.varValue), 2)))
print("X2: {}".format(round(pulp.value(X2.varValue), 2)))
print("X3: {}".format(round(pulp.value(X3.varValue), 2)))
print("X4: {}".format(round(pulp.value(X4.varValue), 2)))
```

```
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: pulp in /usr/local/lib/python3.9/dist-packages (2.7.0)
Model Status: Optimal
Optimal Solution:
Objective value: $0.23
X1: 5.47
X2: 4.57
X3: 15.38
X4: 19.58
```