Addressing the challenges of Global Sulphur Cap 2020: case study Indonesian tanker shipping

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Abstract. Global Sulphur Cap 2020 (GSC 2020) is a policy that regulates the limitation of sulphur content in ship fuel to meet the global standard of 0.5% starting on January 1st, 2020. This new regulation creates new challenges faced by shipping companies, in particular those which operate ageing ships or operating ships in the so-called Environmental Control Areas (ECA). Five technological options to encompass the GSC 2020 issues are deploying one of three scrubber systems, or switching to environmentally friendlier fuels, i.e. MGO or LNG. The paper outlines a case study of an Indonesian shipping company operating eleven ships, nine tankers and two container ships, with an age between two and 29 years of age. The Multi-Attribute Utility Theory is deployed to provide a recommendation on the best option.

1. Introduction

The International Maritime Organization (IMO) set a new regulation called Global Sulphur Cap 2020, in 2016 [1]. The Global Sulphur Cap 2020 is a policy that regulates ship fuel sulphur content in order to correspond with the global standard. It regulates the prevention of air pollution from ships, particularly sulphur oxide (SOₓ) pollution [2]. The Global Sulphur Cap 2020 stipulates that all international shipping merchants of the countries having ratified MARPOL Annex VI that cross the so-called Emission Control Area (ECA) waters, should use fuel with sulphur content of maximum 0.5% m/m starting on January 1st, 2020, as shown in Figure 1. ECA’s sea areas in which stricter controls were established to minimize airborne emissions from ships as defined by MARPOL Annex VI.

For the implementation of Global Sulphur Cap 2020, IMO provides three alternatives for ships to meet with the 0.5% m/m sulphur content limit. The first is to use a scrubber (exhaust gas cleaning system) if the fuel does not meet with the IMO sulphur content standards. The second is to switch the ship fuel to that of a lower sulphur below or equal to 0.5% m/m. The third alternative is the use LNG (Liquefied Natural Gas) as the ship fuel. The implementation of each alternative would certainly have an impact on shipping companies both in economic terms due to incremental sea transportation costs and in operational terms.

The purpose of ECA establishment is to reduce emissions in a predetermined sea area. ECA’s are selected based on the density of sea traffic, oceanographic and ecological conditions [3]. Currently, ECA covers the Baltic Sea, North Sea region, North American territory, including coastal areas outside of the United States and Canada, the United States Caribbean Sea region around Puerto Rico and the United States Virgin Islands. In the future, the following areas would impose an ECA status, namely Singapore, several regions of China, the Mediterranean Sea, the Tirenia Sea and the Gulf of Mexico, see Figure 2.
A majority of Indonesian tankers consist of a fleet of over 20 years old. This old tonnage with higher fuel costs would suffer very much from the implementation of the new regulation. The objective of the study is to obtain insights on the available methods to meet the requirements. Furthermore the study aims to deliver a recommendation on the best mitigation method to be selected, considering the operation areas of the fleet. A case study on the fleet of tanker and container ships of a prominent Indonesian shipping company in Jakarta. By having this, the study could be used by the shipping company to address the GSC 200 challenges economically.

2. Methodology
The case study is conducted an ageing part of the fleet of a shipping company in Jakarta. The fleet in concern consists of nine tankers and two container ships. The analysis starts with computing the transportation costs, and it is followed with identification of their major cost component.

Identification of choices available to address the GSC 2020 challenges is made. The choices are scrubber installation and fuel type switch. Three types of scrubber systems, namely open loop, closed loop and hybrid systems are considered. Whilst the switch to another fuel types, using Marine Gas Oil (MGO) and Liquified Natural gas (LNG) are considered. All the five options mentioned above pertain direct economic consequences, namely investment and operating costs.

Four scenarios are developed to address the implementation of GSC 2020 for the above case study, namely:

- Scenario-1: Fleet of up to 25 years, operating in ECA area, where wash water discharge is prohibited.
- Scenario-2: Fleet of up to 25 years, operating in non-ECA area, where wash water discharge is allowed.
- Scenario-3: Fleet of up to 30 years, operating in ECA area, where wash water discharge is prohibited.
- Scenario-4: Fleet of up to 25 years, operating in non-ECA area, where wash water discharge is allowed.

Finally, recommendation for each scenario is proposed by using the Multi-Attribute Utility Theory [5]. Four criteria namely Net Present Value (NPV), Benefit Cost Analysis (BCA), annual transportation costs and accumulative total transportation costs during the remaining life time of the ship.

3. Ship and Operating Conditions

3.1 Ships’ Age, Engine and Fuel Consumption

The technology of ship’s main engine and machineries has progressed very much. The technological development has been directed towards increasing the engine’s efficiency. Table 1 shows us that, today’s engines consume approximately 80% of those one hundred years ago [6].

| Year         | SFOC (grams/kWh) |          |          |
|--------------|------------------|----------|----------|
|              | Main Engine      | Auxiliary Engine |
| 1900 - 1973  | 210              | 225      |
| 1974 - 1979  | 200              | 215      |
| 1980 - 1984  | 190              | 205      |
| 1985 - 1989  | 180              | 195      |
| 1990 - 1994  | 175              | 190      |
| 1995 - 1999  | 170              | 185      |
| 2000 - 2010  | 168              | 183      |
| 2011 - 2015  | 165              | 180      |

The growing size of ships increases the engine power installed on board the ship, which in turn increases the emission of the ships, as shown in Figure 3 [6].
3.2 Operating Conditions

Table 2 shows a list of countries prohibiting the water discharge. For Indonesian ships in this case study, their trading area covers Singapore, which is one of the world’s maritime hub. ECA has been implemented here. At present, Singapore is one of areas sharing the same border with Indonesian waters. Regulations implemented by Singapore should be considered well, as many Indonesian ships pass its waters for their both domestic and international trades. The Indonesian ships passing through Singaporean waters are no longer allowed to discharge wash water. This leads to the choice of scrubber technology or even change of fuel.

Table 2. Countries implementing the wash water discharge ban

| No | Area/Country Name                         | No | Area/Country Name         |
|----|------------------------------------------|----|---------------------------|
| 1  | Hawaii, United States of America         | 7  | Latvia                    |
| 2  | California, United States of America     | 8  | Lithuania                 |
| 3  | Connecticut, United States of America    | 9  | United Arab Emirates      |
| 4  | Ireland                                  | 10 | India                     |
| 5  | Belgium                                  | 11 | China                     |
| 6  | Norway                                   | 12 | Singapore                 |

4. Technological Options

4.1 Scrubber Systems

A scrubbers or an Exhaust Gas Cleaning Systems (EGCS) is an equipment which removes particulate matter and harmful components, such as sulphur oxides (SOx) and nitrogen oxides (NOx) from the exhaust gasses generated as a result of combustion processes in marine engines. A scrubber is also viewed as an instrument to control pollution, see Figure 4.

A scrubber system treats exhaust from engines, auxiliary engines and boilers, onshore and onboard marine vessels. The objective of its installation is to minimize hazards by toxic chemicals exposed to human life and the environment.

Therefore a scrubber seems an appealing candidate to address the GSC 2020, due its lower investment and operating costs. There are three scrubber systems, shown in Table 3. In open loop system, wash water is continuously discharge to the sea, whilst the remaining is not.
The requirements of tank addition differ depending on the type of scrubber technologies to be selected. These are the requirements of tank addition of open loop (sea water scrubber / SWS), closed loop (fresh water scrubber / FWS) and hybrid scrubber (HS) are detailed by in the following Table 4.

Table 4. Requirements of tank additions for each scrubber type [9]

| Scrubber Type   | Tank Addition Requirements                                      |
|-----------------|-----------------------------------------------------------------|
| Open Loop       | Sludge Tank                                                     |
| Closed Loop     | NaOH’s Tank+Sludge Tank+Bleed-off Tank+Additional Fresh Water Tank |
| Hybrid          | NaOH’s Tank+Sludge Tank+Bleed-off Tank+Additional Fresh Water Tank |

The provision of a scrubber consists of the costs for purchasing the equipment, its engineering design, documentation and labor [8]. The following equation expresses the capital costs for the provision of scrubber.

\[ BMS = A + B + C + D + E \] (1)

where:

- \( BMS \) = Scrubber Total Capital Cost
- \( A \) = Equipment Cost
- \( B \) = Installation Cost \((0.8 \times A)\)
\[ C = \text{Engineering Design Cost} \ (0.09 \times A) \]

\[ D = \text{Documentation Cost} (0.02 \times A) \]

\[ E = \text{Installation Worker Wages} \ (0.01 \times A) \]

A scrubber installation affects few aspects of operations. Labour and maintenance activities intensify, a part of its installation could occupy cargo spaces which would reduce the income from freight, and additional costs for disposing sludge, handling costs for NaOH liquid treatment and costs for additional water provision. The sum of all these costs is called additional operating costs (AOC). Depending on the the types of scrubber the additional operating costs (AOC) are [9]:

\[ \text{AOC}_{\text{Open Loop Scrubber}} = LC + MC + LF + SDC \]

\[ \text{AOC}_{\text{Closed Loop Scrubber}} = LC + MC + LF + SDC + NT + AT \]

\[ \text{AOC}_{\text{Hybrid Scrubber}} = LC + MC + LF + SDC + NT + AT \] (2)

where:

\[ AOC = \text{Additional Operating Costs} \]

\[ LC = \text{Labour cost (2\% of engineer crew wages assumption)} \]

\[ MC = \text{Maintenance cost (3\% of scrubber price assumption)} \]

\[ LF = \text{Loss in freight} \]

\[ SDC = \text{Sludge disposal cost} \]

\[ NT = \text{NaOH liquid cost} \]

\[ AT = \text{Additional fresh water cost} \]

4.2 Fuel Switch to MGO

Fuel switching to MGO on oil tanker ship is based on several technical aspects such as the age of the ship, sulphur content and the type of engine used. In term of ship age, for older ship, there is a less time to return on investment when using a scrubber. For older ship, it can be switching fuel to use cleaner alternative fuels such as MGO [1]. In term of sulphur content, it is known that the value in MGO fuel is 0.1\% m/m. This value satisfies the sulphur content limit both globally and ECA.

The technical aspects based on engine type are differ between slow speed diesel, medium speed diesel or high speed diesel engine. Manufacturers of diesel engines usually specify the minimum and maximum viscosity values applied to fuel. The viscosity value are applied to each engine type as follows.

- Slow Speed Diesel (SSD) is an engine that has speed of less than 400 RPM and the value of fuel viscosity is minimum 2 cSt.
- Medium Speed Diesel (MSD) is an engine that has speed between 400 to less than 1,400 RPM and the value of fuel viscosity is varied from 1.8 to 3 cSt depending on the brand and type of engine used.
- High Speed Diesel (HSD) is an engine that has speed of more than 1,400 RPM and the value of fuel viscosity is varied from 1.4 to 1.5 cSt.

In determining the investment cost of replacing fuel, a calculation is needed related to the total fuel cost required by the ship:

\[ WFO = n \times SFOC \times MCR \times t \times Margin \] (3)

where:

\[ WFO = \text{fuel consumptions (ton)} \]

\[ n = \text{machine (unit)} \]

\[ SFOC = \text{Specific Fuel Oil Consumption (gr/kWh)} \]

\[ MCR = \text{Maximum Continuous Rating of Main Engine (kW)} \]

\[ t = \text{operational time (hour)} \]
4.3 Fuel Switch to LNG

Fuel switching to LNG on oil tanker ship is based on several technical aspects such as the age of the ship, the sulphur content of the fuel and the type of engine used. For older ship, there is a less time to return on investment when using a scrubber. For older ship, it can be switching fuel to use cleaner alternative fuels such as LNG [1]. It is known that the value of sulphur content in LNG fuel is 0% m/m. This value certainly satisfies the sulphur content limit both globally and ECA.

Based on references from the report on Wartsila Dual Fuel Technology, there are three conversion concepts in gas-fueled engines [10]:

- **SG (Spark-Ignited)** engine uses gas fuel.
- **DF (Dual Fuel)** engine uses two different type of fuels.
- **GD (Gas-Diesel or Tri-Fuel Engine)** engine uses three different types of fuel, namely gas and diesel.

The detailed differences of those three types of gas engine are shown on Table 5.

**Table 5. Comparison between gas fueled engines [11]**

| Fuel Type       | SG (Spark Ignited) Engine | DF (Dual Fuel) Engine | GD (Gas-Diesel) Engine |
|-----------------|---------------------------|-----------------------|------------------------|
| Engine Conversion | Only gas (LNG)            | LNG/MDO/MGO/HFO       | LNG/MDO/MGO/HFO        |
|                  |                           | - Suitable for retrofit vessels. | - Suitable for retrofit vessels. |
|                  |                           | - Require additional space in the engine room. | - Do not have to increase the space of the engine room or engine conversion only |

In the case study of alternative replacement of LNG fuel, it is assumed that the main engine or dual fuel engine uses LNG and HFO fuels and the auxiliary engine that is not converted still uses HSD fuel. Based the Conversion of the Badger LNG of the United State Environmental Protection Agency in [12], it was stated that there were three additional cost components in the alternative procurement of LNG fuel replacement, namely capital costs for providing engine conversion, operational costs which comprise of additional annual inspection costs and fuel costs which affects the increase in travel costs. The breakdown of capital costs on LNG conversion is shown below:

\[
BML = AA + BB + CC + DD + EE + FF + GG + HH + II + JJ
\]

where:
- **BML** = LNG Conversion Total Capital Cost
- **AA** = LNG Tank Price
- **BB** = Dual Fuel Machine Price
- **CC** = LNG Piping Cost
- **DD** = Additional Certification Cost (15-20% of LNG tank price)
- **EE** = Machinery Component Cost
- **FF** = Docking Cost
- **GG** = Fuel and Fire Detection Checking Cost
- **HH** = Installation Cost
- **II** = Scrap Worker Wage
- **JJ** = Welder Wage
The additional breakdown of operational costs in LNG conversion is shown below:

\[ BOL = BI \]  \hspace{1cm} (5)

where:

- \( BOL \) = Additional Operational Cost of LNG Conversion
- \( BI \) = Annual Inspection Cost

The fuel specifications that commonly used on ships are shown on Table 6.

### Table 6. Fuel Specifications [13]

| Fuel Type                  | ISO Category | Viscosity (cSt) | Sulphur Content (%) | Density (ton/m³) |
|----------------------------|--------------|-----------------|---------------------|-----------------|
| Heavy Fuel Oil (HFO)       | Residual (RMG) | 380             | 3.5%                | 0.991           |
| Marine Gas Oil (MGO)       | Distillate (DMZ) | 3               | 0.1%                | 0.89            |
| Marine Diesel Oil (MDO)    | Distillate (DMB) | 11              | 1.5%                | 0.89            |
| High Speed Diesel (HSD)    | Distillate (DMA) | 2               | 0.5%                | 0.89            |
| Medium Fuel Oil (MFO)      | Residual (RMG) | 380             | 3.5%                | 0.991           |
| Liquefied Natural Gas (LNG)| Liquefied Natural Gas | 0.146(1)       | 0%(4)              | 0.47(3)         |

5. Economic Evaluation

The feasibility from a business is can be calculate by using Benefit Cost Ratio (BCR). This ratio is obtained by dividing the present value of the benefits flow (PV or Present Value) with the current value of the flow cost, which aims to determine the ratio between the amount of costs incurred on a business against the benefits got. Mathematically, the BCR calculation can be formulated as follow:

\[
BCR = \frac{\sum_{t=1}^{n} B_t (1 + i)^{-t}}{\sum_{t=1}^{n} C_t (1 + i)^{-t}}
\]

(6)

where:

- \( BCR \) = Benefit Cost Ratio
- \( B_t \) = Benefit on year-t
- \( C_t \) = Cost on year-t
- \( I \) = Interest rate (%)
- \( T \) = time (year-1 to year-n)

The indicators of eligibility based on \( BCR \) are, if \( BCR \) is greater than one \((BCR > 1)\) then the business is feasible to run. Conversely, if the \( BCR \) is smaller than one \((BCR < 1)\) then the business is not feasible to be run.

6. Discussions

6.1 Analysis of the Existing Condition

The sea transportation cost of a tanker is calculated, in order to analyze the present operational condition. The following case study analyses a tanker voyage which carries aviation fuel. The tanker ship route are from TTU Balongan in Indonesia to Jurong Harbor in Singapore and return to TTU Balongan.

After the value of each component of sea transportation cost is known, it can be made a comparison of component costs from the tanker ship which operated by the biggest national shipping companies in Indonesia. The comparisons are intended to determine the costs mostly expended in ship operation. The average component of sea transportation costs spent on tanker ship is shown in Figure 5.
Figure 5. The existing condition of sea transportation cost component

Based on the existing condition of sea transportation cost components, the largest cost component of the tanker is voyage cost that consists of fuel costs and port costs. Voyage cost spends about 47% of the total tanker transportation cost.

From the voyage cost component, it can be concluded that the greatest cost requirement is the fuel cost, that spend about 90% of the total tanker voyage cost as exhibited in Figure 6.

Figure 6. Voyage cost components

Technical consequences following the any option to meet GSC 2020 are considered. Five options are available, namely the installation of a scrubber, of either open loop, closed loop or hybrid type, and fuel switch either to MGO or LNG, see Table 7.

Table 7. Technical consideration for each option [10]

| Scrubber Installation (Open Loop, Closed Loop, Hybrid) | Fuel Switch to MGO | Fuel Switch to LNG |
|-------------------------------------------------------|--------------------|--------------------|
| Ship Engine Power                                      | Ship Age           | Sulphur Content    |
| Shipping Area                                          |                     | Engine Type Suitability Check | Engine Conversion |
| Scrubber System                                        |                     | Check               |                    |
| Tank Addition                                          |                     |                     |                    |

In the economic analysis, it is necessary to calculate the sea transportation cost for each alternative. It supposed to find out the details of expenses used when procure the additional investments on retrofit vessels which are analyzed according to case studies. The detailed economic analysis of each alternative should consider three factors below:
a) Installation of all three types of scrubber systems, i.e. open loop, closed loop and hybrid, would require additional to capital costs and operational cost, see equations (1 & 2).

b) Fuel switching to MGO would drive additional voyage costs that can be calculated, see equation (3).

c) Fuel switching to LNG would drive additional capital costs according to equation (4), operational costs according to equation (5), and fuel costs according to equation (3).

Figure 7. Percentage of total cost increase

Every technological option provides its respective consequences to the environment. The emission reduction which could be achieved is shown in Table 8. To be noted that the amount of emissions of the main engine that still remains quite a lot is on the alternative scrubber (open loop, closed loop, hybrid) because it still use high sulphur fuel. If it is intended to effectively reduce the amount of emissions then it is suggested to replace the fuel to use MGO or dual fuel (LNG and MGO). However, based on the remaining emissions in each alternative it is shown that each alternative is able to meet the sulphur content standards of 0.50%, both on the main engine and the auxiliary engine. Meanwhile, to meet the ECA sulphur content limit of 0.10%, the use of HSD fuels in alternative auxiliary engines for dual fuel engines will not be acceptable.

Table 8. Residual emission level in ship engine [13]

| No | Alternative         | Main Engine Fuel | Emission Reduction | Residual Emission |
|----|---------------------|------------------|--------------------|-------------------|
|    |                     | Type             | Emission Level (ppm) | % | ppm | ppm | % Sulphur |
| 1  | Open Loop Scrubber  | HFO 3.5%         | 35,000             | 97.1% | 33,985 | 1,015 | 0.102% |
| 2  | Closed Loop Scrubber| HFO 3.5%         | 35,000             | 97.1% | 33,985 | 1,015 | 0.102% |
| 3  | Hybrid Scrubber     | HFO 3.5%         | 35,000             | 97.1% | 33,985 | 1,015 | 0.102% |
| 4  | Low Sulphur Fuel    | MGO 0.1%         | 1,000              | 96%  | 960   | 40   | 0.004% |
| 5  | Dual Fuel Engine    | LNG 0%           | 0                  | 100% | 0     | 0    | 0%     |
|    |                     | HSD 0.5%         | 5,000              | 70%  | 3,500 | 1,500 | 0.15%  |

6.2 Proposed Solutions

Multi-Attribute Utility Theory (MAUT) is a decision-making approach that is used to convert some decisions into a numerical value between scale of 0 until 1, where 0 representing the worst choice and 1 for the best choice [5]. This approach allows the direct comparison between various values. The final
result is a ranking order of alternative evaluations that illustrates the choices of the decision makers. For the calculation can be formulated as follows:

\[
v(x) = \sum_{i=1}^{n} w_j x_{ij}
\]  

(7)

Where \(v(x)\) is the evaluation value of an object to \(i\), while \(w_j\) is the weight that determines the value of how important the \(i\) element than the other elements. Whereas \(n\) is the number of elements, namely 4. This represents respectively \(NPV\), \(BCR\), annual transportation cost and the accumulative transportation costs till the remaining lifetime of the ship. Each weight is 25%, its total weight is 1. The results are shown in the following Tables 9-11.

Table 9. Selected alternative of Scenario-1 & -2

| No  | Ship’s name   | Age (years) | Type         | Best option          | MAUT score |
|-----|---------------|-------------|--------------|----------------------|------------|
|     |               |             |              | Open Loop Scrubber   |            |
|     |               |             |              | Closed Loop Scrubber |            |
|     |               |             |              | Hybrid Loop Scrubber |            |
|     |               |             |              | MGO                  |            |
|     |               |             |              | LNG                  |            |
| 1   | SINAR BINTAN  | 17          | Container Feeder | X                     | 0.397      |
| 2   | SINAR MALUKU  | 15          | Oil Tanker    | V                     | 0.279      |
| 3   | SINAR BANDA   | 14          | Container Feeder | V                     | 0.443      |
| 4   | SINAR AGRA    | 13          | Oil Tanker    | V                     | 0.259      |
| 5   | SINAR BUSAN   | 13          | Oil Tanker    | V                     | 0.258      |
| 6   | SINAR MATARAM | 10          | Oil Tanker    | V                     | 0.299      |
| 7   | SINAR MOROTAI | 2           | Oil Tanker    | V                     | 0.199      |

Table 10. Selected alternative of Scenario-3

| No  | Ship’s name   | Age (years) | Type         | Best option          | MAUT score |
|-----|---------------|-------------|--------------|----------------------|------------|
|     |               |             |              | Open Loop Scrubber   |            |
|     |               |             |              | Closed Loop Scrubber |            |
|     |               |             |              | Hybrid Loop Scrubber |            |
|     |               |             |              | MGO                  |            |
|     |               |             |              | LNG                  |            |
| 1   | SINAR BUKOM   | 29          | Oil Tanker   | X                     | 0.344      |
| 2   | SINAR JOHOR   | 28          | Oil Tanker   | X                     | 0.271      |
| 3   | SINAR BONTANG | 27          | Oil Tanker   | X                     | 0.351      |
| 4   | SINAR LABUAN  | 25          | Oil Tanker   | X                     | 0.400      |
| 5   | SINAR BINTAN  | 17          | Container Feeder | X                     | 0.575      |
| 6   | SINAR MALUKU  | 15          | Oil Tanker   | V                     | 0.308      |
| 7   | SINAR BANDA   | 14          | Container Feeder | V                     | 0.575      |
| 8   | SINAR AGRA    | 13          | Oil Tanker   | V                     | 0.310      |
Table 11. Selected alternative of Scenario-4

| No | Ship’s name    | Age (years) | Type       | Best option          | MAUT score |
|----|----------------|-------------|------------|----------------------|------------|
| 1  | SINAR BUKOM    | 29          | Oil Tanker | V                    | 0.397      |
| 2  | SINAR JOHOR    | 28          | Oil Tanker | X                    | 0.271      |
| 3  | SINAR BONTANG  | 27          | Oil Tanker | V                    | 0.351      |
| 4  | SINAR LABUAN   | 25          | Oil Tanker | X                    | 0.400      |
| 5  | SINAR BINTAN   | 17          | Container Feeder | V | 0.575 |
| 6  | SINAR MALUKU   | 15          | Oil Tanker | V                    | 0.308      |
| 7  | SINAR BANDA    | 14          | Container Feeder | V | 0.575 |
| 8  | SINAR AGRA     | 13          | Oil Tanker | V                    | 0.310      |
| 9  | SINAR BUSAN    | 13          | Oil Tanker | V                    | 0.305      |
| 10 | SINAR MATARAM  | 10          | Oil Tanker | V                    | 0.334      |
| 11 | SINAR MOROTAI  | 2           | Oil Tanker | V                    | 0.325      |

7. Conclusions
A number of conclusions that can be drawn from the current study are listed below:

1. Global Sulphur Cap 2000 is viewed as challenges by shipping companies, in particular those which operate aging ships or operating ships in restricted areas, the so-called Emission Control Areas (ECA).
2. Five options addressed to overcome the above challenges are three types of scrubber systems, and shift to environmentally-friendlier fuels, i.e. MGO or LNG.
3. Multi-Attribute Utility Theory has been adopted to rank the options by incorporating the consequences of deploying every option in economic terms namely NPV, BCR, annual transportation cost and the accumulative transportation costs till the remaining lifetime of the ship.
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