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REAL OPTIONS ANALYSIS OF ABATEMENT INVESTMENTS FOR SULPHUR EMISSION CONTROL AREAS COMPLIANCE*

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Abstract. Since the introduction of the Sulphur Emission Control Areas (SECA) regulations in the Baltic Sea Region (BSR) in 2015, the BSR has witnessed high compliance rate. However, a closer look to the situation reveals that the currently preferred compliance strategies depend on low oil price where ship owners shun investments in abatement technologies which may lead into an economic trap in the event of the oil price increase. The research considers incentive provisions for maritime investors who make investment decisions related to clean shipping and maritime fuel management. Traditionally, the financial assessments of these decisions are based on capital budgeting methods comprising cash flow analyses and net present value calculations. The findings reveal that the Real-Option approach represents a more realistic, reliable and promising method for the evaluation of abatement projects, especially under uncertainty and high volatility in material resource markets. The results can be applied to the evaluation of all projects in the maritime industry that depends on the price variation of the underlying asset during a specific period.

Keywords: SECA regulations; maritime investments; Real-Options; Monte Carlo simulation; clean shipping

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1. Introduction

Green and environmentally friendly shipping have received much attention based on concerns for its local and global contribution to air pollution and environmental problems. Therefore, the Sulphur Emission Control Areas (SECA) was implemented targeting reduction of sulphur emissions from shipping (Olaniyi, 2017). International Maritime Organization (IMO) decided that all ships in SECA have to use marine fuels with a lower amount than 0.1% of Sulphur content from January 2015 (IMO, 2015, 2016) to ensure a greener and more sustainable maritime transportation system.

There are three primary SECA regulations compliance options for the ship owners. First, as Turesson and Weddmark (2015) stated, is to switch the use of the marine heavy fuel oil (HFO) to the cleaner low-sulphur fuel such as the Marine Gas Oil (MGO) and Marine Diesel Oil (MDO). The second alternative is to continue with the high-sulphur fuel (i.e. HFO) and installing an exhaust gas treatment system, an abatement technology called the scrubber which gives room for the continuous use of the HFO (Farrell et al., 2002). The third option is to switch to other alternative sources of fuel such as Liquefied Natural Gas (LNG), methanol or hydrogen cells. These alternative fuels are being considered for future solutions to meet the SECA requirements (Turesson & Weddmark, 2015). Olaniyi, Atari and Prause (2018) result also revealed that most of the ships are switching to the use of the low sulphur fuel because it removes the hassles of capital compliance investments. Moreover, Hämäläinen (2016) found out that, in Finland, 45 % of shipping operating costs are fuel costs. This finding makes fuel one of the most critical factor in shipping industry so that the optimisation of fuel consumption as well as the choice of the best alternative for abatement are not only important for environmental reasons but are also crucial for the maritime industry due to economic conditional.

The Global Marine Fuel Trends 2030 study (DNV GL, 2018), affirms that combining the use HFO with an abatement technology is likely the most cost-effective option for the ships for SECA compliance because the MGO is more expensive than the HFO. Furthermore, the limitations associated with the use of the LNG such as insufficient bunkering facilities and the expensive conversion costs for old vessels is also a hindrance (Bergqvist et al., 2015). With this background, the scrubber technology, in the light of different uncertain factors of other low sulphur fuels received much attention over the last years and the number of scrubbers installed on board ships increased slightly (Eelco & Maarten, 2015).

The scrubber technology was initially developed to prevent the pollution problem from the power plants with the first marine scrubber developed in Finland and started operation since 2012 (Matczak, 2013). Through installations on new ships and retrofitting meanwhile, 87 scrubbers were installed by the end of the year 2016 in the BSR (HIS, 2017). Scrubbers are classified as open loop and closed loop, and some of those are built based on hybrid technology (i.e. a combination of the both the open and the close scrubber technology installed on one ship). The open loops are cheaper with lesser operating costs than closed loops. Scrubber installations have sparked a discussion on the ecological implications and specific problems the abatement technology so that Germany and Belgium are not allowing ships to enter their ports, which are operating with an open loop scrubber (Lindstad et al., 2015).

It is no gainsaying that clean shipping initiative demands best business solutions for the maritime industry since the economic impact of the SECA regulations is as significant as the environmental impacts for clean shipping infrastructure investments and development of sustainable business models for public and private maritime enterprises. Making investment decisions require advanced analytical methods because the known traditional methods have many shortages and are not particularly precise when they measure static conditions without forecasting and estimating or taking many parameters in future into consideration (Dixit and Pindyck, 1994). Right decision-making process regarding investments or financing project is essential to creating positive projects economic conditions and this applies to projects with high risks in front lines of technology (Cox et al., 1979).

Accordingly, the SECA regulation and compliance can promote the enhancement of high technology and in response to new needs; the analysis of the actual disposal of the new rationale concerning investment and valuation decisions is needed. Thus, the objective of this work is to provide empirical validation of methods that can solve investors' challenge of SECA compliance investment decisions to avoid loss and maximise profit. Through a case study, the work focuses on the analysis of the historical time series data of fuel prices, scrubber inward investment, operating cost of scrubber-retrofitted ships, as well as on the analysis of the NPV and Real-Option investments calculations. All activities took place in the frame of "EnviSuM—Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies" project sponsored by the EU regional development fund.

This paper intends to assess the economic performance of this innovation project of the shipping companies. Methods for economic analysis are currently the most diffused methods for evaluation of innovation projects (Ryan and Ryan, 2002). Although the existing methods largely differ in their implementation, they all share a common principle, that is, the capital budgeting approach for calculating the economic return of a project as a sequence of discounted cash flows (Chiesa and Frattini, 2009). Besides the standalone practices for analysis of investments and assessment of innovative projects, these traditional techniques are extended in this work through the use of the real-options approaches and dynamic analyses into project evaluation, which considers the value of embedded options and the flexibility of the dynamic process of decision-making (Brealey et al., 2012). The authors also suggest the use of analytical and numerical methods like the Black-Scholes model, binomial model and Monte Carlo simulations to quantify risks and uncertainties associated with the feasibility of investments in scrubber technologies.

The remainder of the paper is arranged in the following manner: In the next section, the authors describe the theoretical framework that forms the bases for this study. The third section presents the empirical methodology described briefly above, with an emphasis on the identification of exogenous parameters related to the study case, the capital budgeting approaches and the real option valuation methods. The fourth section illustrates the case study, layout our estimations and discusses the main results and findings. The last section concludes the article.

2. Theoretical background

2.1. Investment and capital budgeting in scrubber technology

Evaluating corporate investments' value or assessing innovative projects' performance allows managers to effectively improve their business decisions and investment planning, in order to guide the project management, optimize the project efficiency and maximize the project economic return. Finance theory states that expected (future) cash flows (CF), either the positive or negative income streams an investor would receive from an investment should be discounted at the opportunity cost of capital and adjusted for the time value of money, so as to estimate the net present value of the investment. Thus, the project valuation and the investment decision are made thoroughly.

It is widely recognized that the process facilitating the decision-making is called the Discounted Cash Flow (DCF) method. This method (DCF) is viewed as a plausible and robust approach to quantify the complex and large-scale investment in single parameters (e.g. the net present value—NPV generated by investments to summarise performance indexes that illustrate the attractiveness of the investment (e.g. the internal rate of return—IRR and the profitability index) (Ye and Tiong, 2000; Downes and Goodman, 1998). The reliability of this method is motivated by the fact that its parameters are easily observed and calculated, takes into account the time-dependent value of money and involves predicting cash inflows and outflows related to the investment over its lifespan (Savvides, 1994; among others). In addition, although the existing methods largely differ in their implementation, they all share a common principle, that is, the capital budgeting approach for calculating the economic return of a project as a

sequence of discounted cash flows (Di Lorenzo et al., 2012, Copeland et al., 2010; Chiesa and Frattini, 2009; among others).

On the other hand, the Net Present Value (NPV) is the most commonly used economic approach to evaluate different types of investments (Ross, 1995). It consists of discounting all future cash flows (both in- and out-flow) resulting from the innovation project with a given discount rate and then summing them together as reported in equation 1. The most straightforward rule of the NPV decision is to discard all projects with negative NPVs and undertake all projects with positive NPVs. This type of decision rule ensures that companies maximise value for their investments. Therefore, the merit of innovation is measured considering its contribution to the creation of economic value out of the investment initial cost, i.e. when the NPV is greater than zero. Thus, when applying the NPV approach to the scrubber investments in the shipping industry, the NPV of a scrubber is expressed with the following specification:

$$NPV_t = \sum_{t=1}^T \frac{CF_t}{(1+r)^t} - CapEx_0 \quad (1)$$

In this given formula, CF_t is the expected cash flow generated in year t , representing the savings from operating income at the end of year t , which assumed to be constant over the whole investment period. T is the investment period (i.e. the economic life of a scrubber); r is the risk-free interest rate - usually in financial evaluation, cash flows are discounted at the weighted-average cost of capital (WACC). The term $(1+r)$ is in the finance literature called the discount factor and $CapEx_0$ is the capital expenditure, which corresponds to the initial capital investment in a SOx scrubber. The sum of the discounted values of the cash flows corresponds to the present value (PV) of the inflows sequence.

This approach is risk-adjusted, while other metrics of capital budgeting and performance criteria such as ROI, IRR (Internal Rate of Return) or MIRR (Modified Internal Rate of Return) are not (e.g. Maquieira et al., 2012; Jackson and Sawyers, 2008; Kierulff, 2008). In its basic application the discount rate is calculated looking at the “real” cost of capital employed in the project, that is, by calculating the weighted average cost of equity and debt used to finance the project. This was discussed from theoretical and empirical standpoints in Lifland (2015), Chiesa and Frattini (2009), Myers, et al. (1976), Myers (1972).

However, when flexibility is the core project objective, the standard DCF based method and the NPV indicator underestimate the current value of the investment i.e. the present-worth asset-value, as well as some management options such as sensitivity and scenario approaches and real-option analysis (e.g. Di Lorenzo et al., 2012; Farragher et al. 2001; Copeland, 2001; Ho and Pike, 1998). For instance, Milne and Whalley (1999) discussed that in the event of delayed investment, the future income and option values have to be added to the current year NPV, so to take into consideration compensation of the time-value of money, the asset value should be higher than the commencing investment in the options. This description mainly makes the NPV and standard-DCF method inappropriate and insufficient for evaluating shipping industry investments.

The recognized inappropriateness of the DCF method has necessitated the undertaking of different approaches such as the real-option pricing approach and scenario techniques, which introduced sensitivity analysis, uncertainty associated to the option value and dynamic analysis to the project valuation (Di Lorenzo et al., 2012). Similarly, McLeish (2005), Copeland (2001) and Dixit and Pindyck (1994) have in the past proposed better models based on the NPV indicator, the uncertainties associated with future discounted cash-flows and the probability of the different possible scenarios in different market conditions to evaluate investment appraisal.

Di Lorenzo et al. (2012) and Dixit and Pindyck (1995) propose that the DCF could be used together with Real-Option integration to assess investments plan in a common project or in a high-tech industry where the company want to commercialise new products.

2.2. Real-Option investment evaluation of the scrubber technology

Options trading is a major part of investments in the capital market and its use in the evaluation of investment appraisals is popular. It is important to emphasize that the real option valuation method of investment projects is the extension of financial options theory on real property. Black and Schools (1973) introduced options trading approach into investment appraisal by using the option pricing to evaluate an investment from the zero points of the project. By incorporating a constant price variation of the asset, the money value of the time, the option's exercise price and the option's expiration value, the Black and Schools model calculates the price of a call option and put option in general. Boyle (1977) introduced a new option valuation approach called Monte Carlo Simulation (MCS) where the options traders generate random variables to get the pricing value. With this approach, a simplified simulation is to generate an optional quantity of random variables. However, it has been less acceptable than other approaches for the evaluation of an option price (Glasserman, 2013).

Maritime investors, especially in the shipping industry, appreciate investment decisions, which allow reaction and adaption on price movements for energy commodities since there is no reliable method to predict future prices trend. Thus, the authors propose that it might be of a higher value to obtain a scrubber or install engines that allow them to switch between energy sources to be able to use the most economical fuel. Acciario (2014a) suggested such an abatement technology installation model for maritime industry and used the model to determine the optimal time for deferrals of investments and to evaluate investments at the present or in the future. Acciario investment model was empirically tested and validated with an abatement project on a handy size vessel which was LNG retrofitted. Cox et al. (1979) offered the first simplified future pricing and option valuation model popular among options traders. According to Brach, (2003), the application of Cox's model delivers an expected asset value, the best and worst-case fuel prices scenario as well as the risk-free rate where the investment cost is the same as the exercise price. In the case of a new abatement technology such as the scrubber, investment as an option forces managers to make a decision based on their profit in the first two or three years. However, if the company want to know what could happen within the market in a longer period, then the binomial option-pricing approach would be helpful to illustrate or make investments strategic map where it shows the upper and the lower bands values in the best and worst investment scenarios. Because of this, it has been a more favourable approach among investors. The different fuel scenarios with the highest (V_{Max}) and lowest (V_{Min}) value of saved capital will be calculated to draw the strategic investment binomial lattice (tree) of scrubber technology investment. To acquire the expected asset value of the periodic cash flow C so savings from a constant HFO fuel price over time will be calculated as:

$$C = \text{Max} \left(0; \frac{P \cdot V_{Max} + (1 - P) \cdot V_{Min}}{(1 + r)^t} - K \cdot (1 - r)^t \right) \quad (2)$$

where, K is scrubber costs; r is risk-free rate or WACC (weighted average cost of capital), proxied by the LIBOR rate; T is time at which the option can be exercised; V_{Max} is lattice's up-factor that reflects the maximum value of the saved capital and V_{Min} is lattice's down-factor that reflects the minimum value of the saved capital. In the binomial tree approach (Cox-Ross-Rubinstein) these two factors generate the project's random (present value) of cash flows (CF) so that the original cash flow volatility is preserved. Hence, the next period project cash flow values will move in two directions to conform to the lattice's up and down multiplicative factors and expressed as follows:

$$V_{Max} = e^{\sigma\sqrt{\Delta t}} \quad V_{Min} = 1/V_{Max} = e^{-\sigma\sqrt{\Delta t}} \quad (3)$$

where, σ is the volatility of the underlying assets' value, i.e. the present value of cash flows and Δt is one time period.

With this approach, it should be noted that the option value is calculated by applying the risk-neutral probability P of the investment result. The risk-neutral probabilities allow discounting the cash flow and asset over the period at the internal rate of company risk-free added to the cost of the capital. In other words, instead of using the simple decision tree to calculate the option values, a risk-neutral probability decision tree has to be used discounting asset values at the risk-free rate r . The weighted probability P using the actual outcome of the sum of probabilities on upward and downward option values will be:

$$P = \frac{(1 + r) - V_{Min}}{V_{Max} - V_{Min}} \quad (4)$$

Where P is the risk-neutral probability.

Acciaro (2014b) option evaluation model was based on a discrete binomial tree approach and he argued that using Black and Scholes's method as an option-pricing approach is not appropriate for real asset option-pricing in maritime sector due to several reasons, one of which is the difficulty of proving the historical normal distribution of the underlying data.

2.3. Real-Options and deferral investments

A real project is a tangible asset with the same value as a corporate investment opportunity. It means that the integration between DCF and the Real-Option is similar to a call option where the investor has the right but not the obligation to invest in an underlying asset at a specified fixed price during an agreed period of time or at a given date (Cherry, 2007; Hull, 2006; Luehrman, 1998; Natenberg, 1994). As a common managerial option, its use in practice is through an option to defer, i.e. to wait until further information reduces market uncertainty, and an option to abandon, i.e. to dispose of any unprofitable project or investment (Fusaro, 1998; Trigeorgis, 1996).

Fundamentally, the price of an option in both financial and real project reflects the expected future payoff of the underlying asset at the time of exercise where the expected future payoff is discounted back to the present at the risk-free rate revealing the present option value (Fusaro, 1998; Luehrman, 1998). There is an essential acquisition time for the call options, exercising (strike) options time, twin security arbitrage options of selling and buying or lending and borrowing the capital for the investment (Fusaro, 1998; Trigeorgis, 1996). Arbitrage occurs when a security is purchased in a single market concurrently and using the twin security strategy and investment decision at the time of investment is like a mixture of lending and borrowing. Capital investors can thus build a continued duplicating portfolio to hedge the options this way (Poon and Granger, 2003). However, in diverse financial market options, the strike prices (i.e. the price at which the holder of options can buy) are fixed, while in Real-Options acquisition are not constant. The value of the Real-Option also depends on how uncertain costs and future cash flows correlate to each other (Trigeorgis, 1996).

Furthermore, in Real-Options pricing, it is assumed that the twin investment security option exists which would allow the investors to choose between the real projects or invest in two or more securities at the same time. This situation allows the risks and payoff of the projects to better conform to the market, the options and stock risks or gives room to construct a risk-free hedge in a very optimal situation. In financial market options, the strike prices are fixed, while in Real-Option acquisition, the strike time is set for the future (Poon and Granger, 2003). The value of the Real-Option will depend on how uncertain the costs and future cash flows correlate with each other.

Therefore, investors in an uncertain situation can predict the costs of the options accusation that will eventually take place (Bareley et al., 2012). In fact, the situation for Real-Options is different in financials market where the value of the asset is observable at any time of exercise, expiration and sales are well defined (Ho and Liao, 2011).

Notably, the options are essential for the sizeable capital-intensive project because of the proven efficiency in diverse industries to evaluate nuclear plants, airlines, and railroads (Fernandes et al., 2011). They are also crucial for projects involving new products where the acceptance in the market is uncertain and is equivalent to a firm having a portfolio of call and put options (a call option is like restarting an operation when a project is currently shut down while a put option is like shutting down a current project operation) (Bengtsson, 2001). The option to choose when to start a project is an initiation or deferment option. Initiation options are particularly valuable in natural resource dependent companies where a firm can delay purchasing a commodity like a scrubber or change the fuel type it uses until the market conditions are favourable. This is what it means to wait before taking any action until more is known or when the timing is expected to be more favourable (Dixit, 1992). In a typical market, this approach entails understanding when to introduce a new product or replace an existing piece of equipment to increase or decrease the scale of operation in response to demand, which is comparable with the option to expand or abandon which are crucial for after-investment progress (Trigeorgis, 1993).

The key action for the uncertain situation is to be able to delay investment without losing the available opportunity done by creating a call option on the future investment (Myers and Majluf, 1984). The riskiness of cash flow generated by the project can change significantly during the project lifespan and in the case of projects with production facilities. It may not be optimal to operate a plant for a given period if revenues do not cover the variable costs (Grimsey & Lewis, 2002). In this view, if the price of fuel or any other correlated alternative fuel type falls below the cost of initially calculated, it may be optimal to temporarily shut down the engine type and switch to another type of fuel source until the oil price recovers. An electric utility may also have the option to switch between various fuel sources to produce electricity on the ship.

Against this backdrop, this work will be considering a pricing model of options that depend on the approach of Black–Scholes model and the Binomial option-pricing model (i.e. Hull, 2006; Black and Scholes, 1973; Cox and Rubinstein, 2001). The option prices are determined by the simple discounting method with the expectation that the values of each option at the expiration date will be traded using unreasonable risks premiums as discount factors that were to reflect the volatility of the option according to Jensen (1972). However, the Black-Scholes pricing methods of financial asset assume a lognormal distribution of future returns in a continued period of work from Black and Scholes (1973) where they called the practice a diffusion process or a continued and unhindered arrival of information that causes price change with either a constant or changing variance. These price changes are normally distributed or logged to resolve market uncertainties so that investors can make better and informed decision regarding whether to invest or defer (Arriojas & Mohammed, 2007).

In shipping, operators may have a different approach to the investment on prices and project available to provide better insights into market conditions. Aforementioned, they may decide for example to exchange input resources, that is, switch from one energy form to another or from one type of engine and fuel to another. The commodities between the two include the following generic basics: investment ambiguity, irreversibility, the ability to choose between two or more alternatives (Black and Scholes, 1973).

Following the general option-pricing model of Black and Scholes (1973) and upward and downward probability (this will replace later by a real value to the main formula), investment opportunity in a scrubber technology can be modelled as a call option on the net present value of the expected future revenues from the operating scrubber gas treatment system. This offers the option to invest or postpone regarding the circumstances that affect the formation of the net present value of this project. Therefore, the price of the call option is estimated by solving the following nonlinear equation:

$$\text{Option Call Price} = S_0 N(d_1) - Ke^{-rT} N(d_2) \quad (5)$$

Where $N(d_1)$ and $N(d_2)$ denominate the standard normal cumulative distribution function and e is Euler's constant. The formulas for d_1 and d_2 are given as follows:

$$d_1 = \frac{\ln\left(\frac{S_0}{K_t}\right) + \left(r + \frac{\sigma^2}{2}\right) \times T}{\sigma\sqrt{T}} \quad d_2 = d_1 - \sigma\sqrt{T} \quad (6)$$

Where C is the value of a call option. S_0 is the present value of future cash flows from the investing in the scrubber (i.e. the expected revenues from the operational risky investment in scrubber). T is option's time to maturity or expiration (i.e. the length of time option is viable). $N(x)$ is the cumulative distribution for the standard normal distribution. σ the riskiness of the scrubber, the volatility of the worst- and best-case scenario of the investment (i.e. the standard deviation of the expected rate of return on S). K is the option's exercise price at the end of the period (i.e. the cost of converting the investment opportunity into the option's underlying operational project) and d_1 , d_2 are deviations from the expected value of the normal distribution.

Thus, the proposed pricing in the maritime industry for obtaining new technologies specifically scrubber technology will be calculated as:

$$\text{Option Call Price} = S_0 \times N(\text{pward probability}) - \text{scrubber cost} \times e^{-rT} \times N(\text{downward probability}) \quad (7)$$

In reality, the daily fuel consumption of any ships is a critical factor in calculating the daily and annual cost of fuel consumption, so the time spent within or outside SECA and the time of sail are considered for computation. With these numbers, it would be easy to calculate the value of the cost of fuel consumption easily. If the ship owners decide to operate their ships with fuel change, then, the price spread can be considered for calculations to determine the additional costs of operation and how much savings can be achieved by not changing fuel. The savings are the future cash flow parameters in option value and the cash flows for each period in the traditional methods.

2.4. Real-Options and dynamic analysis: Monte Carlo simulation

The paper empirically examines the joint stance of the DCF and Monte Carlo Simulation (MCS) analyses so to approximate the true NPV of the scrubber investment by incorporating a set of dynamic variables that directly affect the anticipated cash inflow-outflow valuations. The MCS introduces dynamic (probabilistic) analysis into project evaluation by using random inputs in order to model uncertainty and as such, it makes the DCF method more precise for investment appraisal and reliable decision tool in the project risk management (e.g. Di Lorenzo et al., 2012; McLeish, 2005; Ryan and Ryan, 2002). Based on multiple statistical simulations (modelling various scenarios), the MCS technique is likely to be realistic and reflects the dynamic nature of the investment lifespan (e.g. see Ara and Lee (2017)).

More formally, the MCS primarily allows producing an estimate of the project's NPV conditional on the set of random variables drawn from their underlying distribution and to assess the risk associated with the project (i.e. the Value-at-Risk related to the investment). Specifically, in this study, the MCS technique consists on generating stochastic variables by using a random uniformly distributed variable (in the $[0,1]$ interval) to create a scenario analysis utilizing hundreds of possible iterations that continually change the NPV of the asset valuation (e.g. McLeish, 2005; Ryan and Ryan, 2002). The Black and Scholes (1973) model flowed back and the expectation

function of the underlying asset defined (project's value) as a function of a geometric Brownian motion with a drift. Hence, the project's value was pre-specified and assumed to follow a stochastic process as follows:

$$dS_t = \mu S_t dt - \sigma S_t dW_t \quad (8)$$

where S_t is the value of the financial in each time period t , σ its estimated volatility, μ is the drift (yield) measuring the average growth per unit of time, W_t is normally distributed random variable with mean 0 and standard deviation \sqrt{dt} and W is a Brownian motion. Assuming that σ , μ and W_t are constants.

3. Methodology

The study was empirically validated through data from expert interviews, focus group meetings and other case studies done in the frame of EnviSuM–Environmental Impact of Low Emission Shipping project. The case project began in early 2017 until the end of the same year using investments in a scrubber with an installed capacity of 15 KW for the engine power of 48K KW sailing in BSR, mainly between the ports of Helsinki and Tallinn. The daily fuel consumption of the considered ship is assumed to be about 60 mt/day for 350 operating days/year.

The study reviews the compliance investment of a scrubber retrofit with a continuance use of IFO380 or an engine upgrade that involves the boiler and other necessary equipment for LSMGO or ULSFO with 0.1% Sulphur content. A case study was constructed to project real-life scenario to evaluate the scrubber project investment feasibility. The empirical data was used to determine the costs build-ups of the scrubber technology using the conventional investment evaluation tools, i.e. NPV, IRR, MIRR and the payback period comparable to using the proposed real options model. Afterwards, the result of the comparative analysis was used to determine which of the investment evaluation tool is most promising for SECA compliance investment decisions to avoid loss and maximise profit.

3.1. Case Study: application of Real-Option methodology to a maritime investment project

Investment evaluation with the Real-Option approach is not widespread in the maritime industry, and existing literature mostly used the real-option investment evaluation in mining, power plants and new sustainable energy resources with only a couple of research in the maritime industry working on LNG evaluation. With this investment evaluation approach, the authors made a qualitative analysis of the case in the shipping industry. The presented case study addresses an investment project of scrubber abatement and its evaluation. For this study, two evaluation methodologies were compared: the traditional NPV and the ROA (using Black and Scholes model, Monte Carlo method and Binomial option-pricing).

3.2. Project characteristics and descriptive

The cost of a new standard open loop 15 MW scrubber system for the mentioned ferry RoPax type sailing within SECA in the BSR with two main engines is roughly 5.5 million €. The price of a scrubber installation is calculated based on the ship engine power and the number of main engines. Results from the experts' interview indicated that an upfront investment for a ship with two powerful engines required a scrubber cost of €5.8 million. Usually, the flat rate of the scrubber initial cost start from over €2 million depends on the ship design and the choice between the dry or wet (open/close/hybrid loop) scrubber system. The design of the scrubber is usually tailor-made and is unique for every ship.

Half of the total costs are estimated as the actual cost while the other half is designated for installation. At the time of scrubber installation, the ship will be out of service for more than thirty days, involving fundamental construction

changes, commissioning, testing and training. The estimated cost of maintenance is approximately 20 000€/yr. The scrubber system was created using Caustic Soda (NaOH) solution, which is easily within reach globally.

The quickest approach to procure the scrubber chemicals is to order the needed amount of tank cars to the port that the vessel will visit. The cost of materials depends on where the chemical is purchased, and the delivery time, however, the usual price for NaOH was around 300 €/t in 2017. If the ship scrubber system running is a closed loop mode, the costs of operation include a bleed-off treatment unit (BOTU) for the water treatment. This unit usually consumes additional chemicals to complete the cleaning circle adding an operating cost that includes flocculent or coagulant additives. Sometimes to calculate the extra expenses and operating cost, a 2% maintenance and extra operation cost is added to the annual operating costs.

The scrubber has a lifespan of 15 years and the economic lifetime of the ship is 25 years (Atari and Prause, 2017). Some parts of the scrubber may have a shorter lifetime, which would require replacing with spare parts before the machine span life is over. For investment appraisal, it is crucial to predicting the risk-free rate as well as the cost of capital. Mkouar and Prigent (2014) explained that the primarily driven factor in erratic investment is the interest rate, which influences both the cost of capital and discount rate. Some part of the investments funding is from the company's equity while the remaining funding through bank loans, manufacturer companies or export credit financiers. The subject case is using a bank credit of over 15 years set to be repayable through annual payments from the beginning of the scrubber operations and whose annual payments are subject to an interest rate and an opportunity cost on the capital.

4. Results and analyses

Among the advanced low-gas emission regulations in the shipping industry in the BSR, switching to low-sulphur fuel by installing scrubbers and/or using LNG is gaining widespread acceptance as promising options. Thus, its economic performance should be compared with that of identical without using the scrubber and low-sulphur fuel (i.e. ship using HGO 3.5%S).

The subsequent subsections will present and discuss different calculations methods and the main results for the appraisal of low-sulphur scrubber investment proposals. Importantly, such economic analyses are based only on the baseline results of the first-year cost-benefit evaluation of the project.

4.1. Investments evaluation using conventional methods for evaluation

Undertaking the switch to low-sulphur emission and investment in scrubber technology requires that the shipowner conducts cost-effectiveness and evaluation analyses, and as such evaluate the worthwhileness of installing an exhaust gas cleaning technology.

The conventional methods to evaluate the project viability in this case of study are a set of criteria: the NPV, the IRR, the MIRR, the payback period and the profitability index. These methods are optimistic assumptions because it is improbable that bunker fuel prices would remain constant over a span of 15 years. Hence, in the real world, fuel prices might be characterized by a significant variance over the time, and so the realized future cash flows are not constant over the operational period. Thus, the basic assumptions were slightly modified, to provide NPV and real options valuations with a realistic quantitative outcome. Thus the authors applied a dynamic approach by introducing a random variable to predict future fuel prices.

In this case, the pricing is based on the assumption that the movement of fuel prices follows some sort of random walk and all effective costs and benefits due to the scrubber technology solution adjustment for the annual inflation rate. The success and accuracy of DCF analysis are determined by the choice of concomitant discount rate. A

discount rate of 11% is assumed, which is defined by disregarding the composition of funding sources. This assumption could strongly influence the project results. Therefore, bearing in mind these assumptions, the results of the project evaluation are reported in Table 1.

Table 1. Key input-variables, DCF primary results and criteria for evaluation

Data	Value	Definition/Sources	Measure
Panel A: Inputs and cost-benefit analysis			
CapEx	€5 684 000.00	Annual capital expenditures equal approximatively to the initial price of a scrubber.	
OpEx	€4 238 945.31	Annual operating expenditures of the first operational year.	
Spread-saving	€4 768 908.00	Annual spread savings equal to the daily spread prices between HFO and MGO prices of the first operational year.	
Saving-OpEx	€3 251 344.67	Estimated annual cash flows of the first operational year.	
NPV _{1y}	€-2 432 655.33	The net present value (NPV) of the first operating year, a forward-looking measure of the project profitability, equals the difference between saving-OpEx and CapEx. By default, keeping the NPV without 1y-index.	Equation (1)
Discount rate	11.00%	The Weighted Average Cost of Capital (WACC) is the company's weighted cost of capital that, that includes all capital sources: equity and debts. It proxies the discount rate of the estimated cash flows (i.e. Block, 2011; Bennouna et al., 2010).	Proxy by Treasury bonds with a maturity of 10 years in the EU zone.
Panel B: Conventional investment evaluation indicators			
NPV _{15y}	€22 767 025.57	The net present value (NPV) is the difference between the present value of the cash flows (the benefit) over the project lifespan (15 years) and the cost of the investment (i.e. Maquieira et al., 2012; Viviers and Cohen, 2011; Bennouna et al., 2010).	Equation (1)
Payback Period	1.69	The payback period (PP) is the expected number of years required to recover the original investment (i.e. Hermes et al., 2007; Ross et al., 2004).	$PBP = \frac{I_0}{Cumulative\ CF}$
IRR	56.92%	The internal rate of return (IRR) is the discount rate that equates the present value of cash flows over the whole 15 years and the initial cost of the investment (i.e. Maquieira et al., 2012; Jackson and Sawyers, 2008).	$\sum_{t=1}^T \frac{CF_t}{(1 + IRR)^t} = 0$
MIRR	20.92%	The Modified Internal Rate of Returns (MIRR) is the average annual rate of return that will be earned on investment if the cash flows are reinvested at the WACC (i.e. Kierulff, 2008; Jackson and Sawyers, 2008).	$= \frac{I_0}{\sum_{t=1}^T DCF \times (1 + r)^{t-1}} (1 + MIRR)^T$
Profitability Index	5.01	Profitability Index (PI) metrics the relative profitability of the project to the initial investment cost. It is the ratio of the present value of expected net cash flows over the project's lifespan to the investment cost (i.e. Viviers and Cohen, 2011).	$PI = \frac{\sum_{t=1}^T \frac{CF_t}{(1 + r)^t}}{I_0}$

Source: Computed by authors

Due to the investment-oriented approach of this project evaluation, the economic performance of installing a scrubber is assessed according to several criteria and indicators as shown in Table 1. Panels A and B of Table 1 display the statistics and definitions of all the input-data, indicators and indexes used for investment evaluation and economic performance assessment of the study case. Panel A reports the inputs of the investment evaluation and the baseline results of based on the estimations cost-benefit of the first operating year; whereas, Panel B displays the conventional investment evaluation criteria based on the overall project lifespan.

Speaking about the capital costs of a sulphur scrubber investment for our particular ship case, Table 1 (Panel A) shows that the initial cost of the equipment (i.e. scrubber price) equals approximatively to €5.68 million. It is

noteworthy to say that the price of a scrubber tends to largely vary depending on the scrubber engine installed power and size, as well as the specific of ship operating fuel consumption.

The results of the costs analysis for the scrubber technology gives interesting findings of the project investment feasibility. First, the estimated annual scrubber capital expenditures (CapEx) are in the order of €5.68 million the first operating year. In addition to the price of a scrubber, the CapEx includes the costs of installing an exhaust gas cleaning technology on board the vessel (e.g. internal combustion engine, piping, etc.), start-up costs (10% of total capital costs) and other additional costs related to the engine power (weighted by 58 coefficient) and the unit-fuel cost (weighted by 0.5%). The additional capital expenditures are relatively insignificant compared to the initial price scrubber. For conveniently, we retain that the scrubber price proxies CapEx. The estimated annual scrubber operating expenditures (OpEx) are in the order of €4.24 million the first operating year. These costs incorporate consumable costs: additional scrubber fuel consumption (10% of HFO consumption), scrubber services (2% of investment cost) and other additional operating expenditures related to the vessel engine power and scrubber technology (e.g. sludge disposition in port, cost of chemicals supplies, periodic inspections and repairs, minor tests and adjustments to performance monitoring, water management system, etc.) (IMO, 2015); and financial operating costs: financial-interests costs of scrubber (6% interest rate) and depreciation. All annual operational scrubber expenditures are adjusted to 2% inflation-rate through the investment period. More interestingly, according to DNV GL (2018), the operational costs for methanol are expected to be compared with those for oil-fuelled vessels without scrubber technology. This simply implies that the OpEx costs associated with installing a scrubber technology to comply with the SECA requirements on the BSR could not be considered as a business constraint.

Before proceeding further, it is primarily important to clarify that installing a scrubber might take about 2 weeks to six months, which will be a lost revenue period also called off hiring period (Ruiz-Cabrero et al., 2017). However, this consideration will not be taken independently into account in the costs analyses approach, because it is implicitly considered in the annual scrubber operating costs.

Furthermore, Panel A of Table 1 shows that money-saving capability of the scrubber (OpEx) using low-sulphur fuel and a SO_x scrubber relies on the daily spread prices between HFO and MGO prices. The authors followed a dynamic-based approach and construct the average fuel prices on the observed daily fuel prices over four years (2013–2017), i.e. using the average annual prices and the annual volatility of prices. On average, the daily spread prices are close to €214 with €52 standard deviation over the period spanning from 2013 to 2017. The spread prices were relatively constant, high and less volatile for this period of study; though, the HFO prices drop to €81/bbl at the beginning of 2016.

Against this backdrop and statistics, the authors assess how OpEx and CapEx contribute to the total investment in a scrubber and the feasibility of switching to low-sulphur fuel as well as the scrubber adoption. Similarly, the results show that the relative operating expenditures (OpEx) and the relative capital expenditures (CapEx) to the investment cost of installing scrubber (i.e. the price) are around 15% and 13%, respectively; which cannot be economically seen as a burden for the feasibility of the business.

From this, the result in Panel A suggests that the annual spread savings, due to this shift to low-sulfur fuel, is €4.77 million; and thus the balance of the cost-benefit analysis, i.e. the saving-OpEx indicator, accounts for approximately €3.25 million and the net present value (NPV) of the first is €–2.43 million.

Alternatively, the discount rate is fixed as an imputed data; while the conventional criteria of the investment evaluation: the NPV_{15y.}, discounted payback period, the IRR, the MIRR and the profitability index are calculated based on the expected future cash flows, occurring at the end of each year over the investment lifespan (i.e. 15 years). In this case, the expected cash flows are estimated based on fuel prices predictions, annual predicted spread savings (HFO versus MGO costs), annual OpEx and annual CapEx expenditures.

Results in Panel B of Table 1 show that the project of a ship scrubber has a positive present value, which reveals that the wealth generated by this investment is attractive and economically viable. The project will, therefore, raise the value of the shipping company (by €22.22 million euros), which is the financial objective of the shipowners. Hence, the conclusion is that installing a scrubber is relevant and should be undertaken and can be implemented successfully. Interestingly, the initial investment in the scrubber is recovered during the second year and the investment payback occurred after 1.69 years (i.e. break-even point). By implication, this means that the operating costs and the capital expenditures are recovered by the income inflows generated by the project to break even within approximately two years. Furthermore, the results show that the IRR equals to 57% and MIRR equals to 21%, supporting the acceptance of the scrubber investment since these rates exceed the cost of capital, i.e. indicating that the benefits exceed the WACC. MIRR is substantially lower than IRR since the MIRR assumes that project cash flows are reinvested at the cost of capital (instead of the project's own IRR). Lastly, the profitability index shows that the relative profitability of the project is greater than the threshold value of 1-one. Thus, the scrubber investment is expected to produce €5.01 cash inflows for each €1 of investment.

However, production uncertainties were not considered in this evaluation of performance, though it has to be considered carefully, although the NPV calculation only contains the endogenous value of the scrubber investment. As previously stated, this evaluation can be regarded as the first step leading toward real options valuation (ROA), as the ROA is used to overcome those uncertainties. Thus, the application of ROA in evaluating this project will be presented in the next section.

4.1. Investment evaluation using the ROA (Real Options Analysis)

In the application of the ROV (Real-Options Valuation) to evaluate the project using the binomial approach and the Black & Scholes model, two assumptions are taken into account. First, all data provided by traditional evaluation methods are considered, all estimations are conducted based on the cash flow of the first operating year. Other necessary data are unavailable such as future oil price and future scrubber price; however, since the primary objective of this study is to compare traditional investment evaluation method with the ROA methods, these drawbacks may be disregarded.

In contrast to the ships' operational costs, the cost of the scrubber itself is not usually affected by high levels of uncertainty. As a simplified assumption, other uncertainties such as technological changes or environmental policies were not considered. Moreover, since in the case of fuel switching, fuel costs will not have a significant impact on operating costs their values were not introduced. Thus, the primary uncertainty factor is the volatility of fuel prices. The prices considered were the fuel prices of long-term contracts and the average price of the EU main ports for the three years 2015, 2016 and 2017. For the research, spot prices were not included because they may have been strongly influenced by short-term factors such as demand and supply, new regulations, etc. Mean and standard deviation of 963 days IFO380 prices were calculated using yearly-basis rolling windows, reaching 399 €/mt and 178 €/mt, respectively. Then, a simulation with 1000 interactions was conducted to calculate the fuel volatility. The results show an annualized standard deviation of 31.44% approximately, corresponding to the project projected volatility.

It should be noted that investment in a scrubber is not implemented in phases, i.e., the probability of stopping scrubber running after its start-up is low. Given the current economic situation, policymakers may not willingly support its development or make it a priority. More so, legislation could change in the coming years, limiting the feasibility of the scrubber project making the cost of a new scrubber installation or retrofit unstable. In a worst-case scenario, the cost could still be subject to ship-freight rate uncertainty as well as fuel prices in the open market. Therefore, the option of deferring the project within one year can be considered and is justified by the high uncertainty of regulatory change.

Therefore, for the scrubber investment, a deferral option corresponds to a call option, where the decision for a present investment will be taken if the NPV of the scrubber project exceeds the value of the option. These options are typically evaluated through the binomial tree, developed by Cox, et al. (1979). The parameters used to build the tree are displayed in Table 2.

Table 2. Inputs for the Real-Option Analysis

Input data	Value		Description
Present value of future cash flows S	€3.25	Million	Saving-OpEx of the 1 st operating year
Volatility σ	31.44%	Annual	Variance of fuel prices
The risk-free rate of return r	11%	Annual	WACC
Time to expiration T	15	Years	Duration
Time step Δt	1	Year	Analysis period
Investment cost K	€5.68	million	Strike price

Source: Computed by authors

The investment horizon in a scrubber is 15 years, the initial outlay is €5.68 million, the estimated cash flows in the first year is \$1.5 million and its uncertainty (volatility) is computed as 31.44%, as shown in Table 1 above. The risk-free rate of returns would represent the return rate of treasury bonds with a maturity of 10 years in EU added to the opportunity cost of capital. The binomial tree results show a possible evaluation of the underlying asset price and the deferral option from left to right. Regarding the underlying asset, the value presented by the first node of the tree is the current price of the underlying asset (i.e. and the end of time t-1). As shown in the table in Table 3, the underlying asset value can increase or decrease depending on coefficients V_{Max} and V_{Min} respectively (see Equation 2).

Table 3. Key parameters of Real Option-Value

Input data	Calculated parameters	Source
Up factor (V _{Max})	2.12	Equation 3
Down factor (V _{Min})	0.47	Equation 3
Risk-neutral probability (p)	0.60	Equation 4

Source: Computed by authors

After identifying inputs factors required for setting up binomial model, the lattice's up-factor and down-factor, the authors thus construct the binomial lattice (tree) for the project's value, that approximates a lognormal distribution, and calculate the asset values on each node of the binomial lattice, using one-year time period. Currently, the present value of net cash flows (estimation of the first-year inflows) is S₀=100m, and the annual volatility of S₀ is $\sigma=31.44\%$. The time of options maturity was divided into several one-year phases. The results of a recombining lattice are displayed below in Figure 1. For analytic purposes, the truncated values of the lattice is reproduced below.

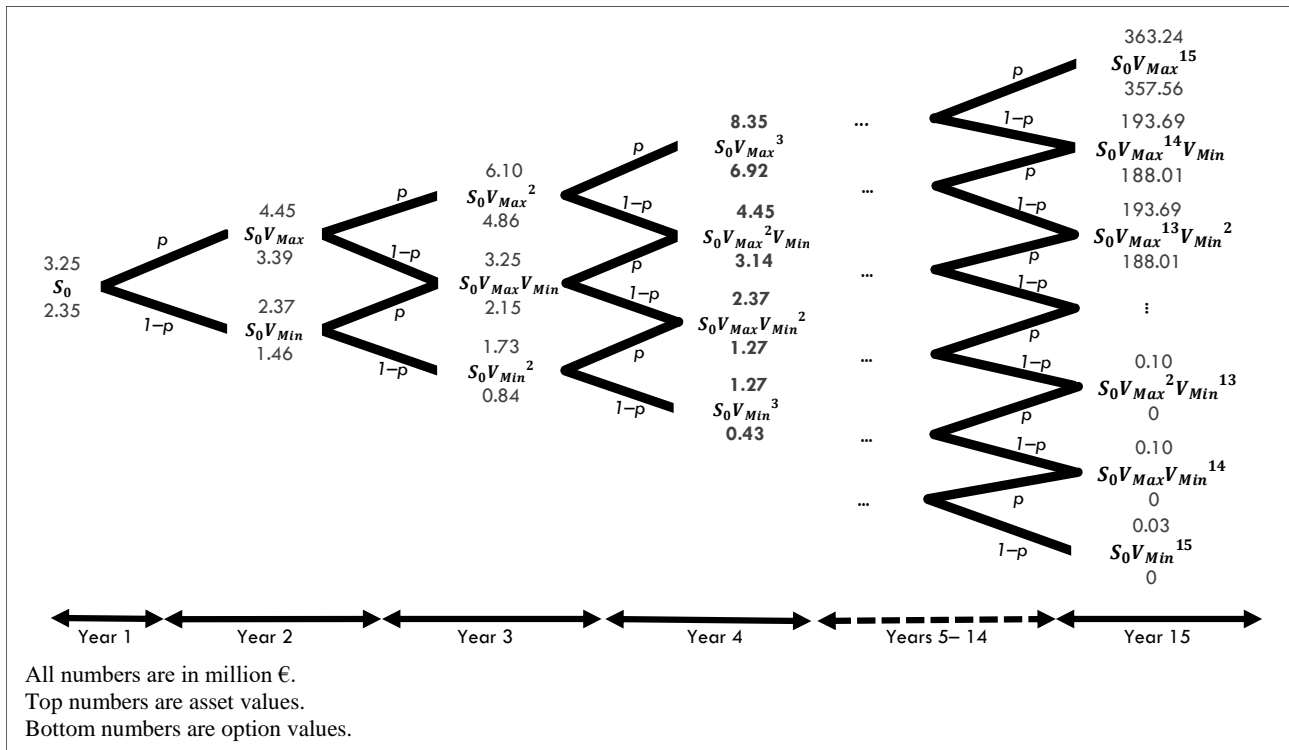


Fig.1. Tree for option to wait
 Source: Computed by authors

Figure 1 forms the diagram of sequential decisions and possible ROA results. Upon completion of each phase, project management has the option whether to invest in a scrubber at that point or delay its implementation and wait until next period. Thus, the binomial lattice (tree) presents the diagram of the next periods' project's random values conform to the value of expected cash flows arising from investing in the scrubber, S_0 , multiplied with the up-factor and down-factor to obtain S_0V_{Max} and S_0V_{Min} . These two factors generate random project's values (i.e. present value of cash flows) so that the original S_0 volatility is preserved. For instance, it was verified that at the end of the first year, the project cash flow values conform to $S_1(up) = S_0V_{Max} = €4.45$ million and $S_1(down) = S_0V_{Min} = €2.37$ million. The investment option's values in the end of the second year show three scenarios: $S_2(up - up) = S_1(up)V_{Max} = €6.10$ million, $S_2(up - down) = S_2(down - up) = S_1(up)V_{Min} = S_1(down)V_{Max} = €3.25$ million and $S_2(down - down) = S_1(down)V_{Min} = €1.73$ million. Additionally, this binomial option-pricing model assigns two associated probabilities to the various nodes that constitute the diagram. Hence, Results shows that the asset value has to be corrected by two coefficients: $p=0.60$ and $1-p=0.40$ (see Equation 4). Finally, as seen in the diagram, the options gave only the right but not the obligation for the manager to make the investment, implying that the payoff scheme to the option holder/ship owner is asymmetric.

Similarly, with the same procedure, the calculation is repeated to show the expected values of option values for every node of the binomial tree until the last year. In Figure 1, the upper numbers on the binominal lattice present expected future asset values over the options life period and bottom numbers indicate option values.

The last column of the binomial tree represents the possible values of the underlying asset at the option maturity date. Since the deferral option is similar to a call option, the last values of the tree are determined by subtracting the values of the underlying asset to the exercise price. The result can fluctuate between $(S - K)$ and 0 with the option value S and the underlying asset price K . The other values are determined by the application of a neutral probability

to each pair of vertically adjacent values. The result shows that a scrubber project value in the first year with the option of delay in the binomial tree is €2.35 million, higher than the NPV of the first year which equals €-2.43 million (this value represents the difference between Saving-OpEx and CapEx of the first-year estimations (see Panel A of Table1)); hence, with high volatility of the market conditions the ROV value exceeds the NPV from investing in scrubber ‘‘today’’. Thus, it is better to postpone the investment decision.

Furthermore, an option value of delay is offered by calculating the difference between the expanded NPV (predict future cash flows, i.e. ROV) and the computed NPV of the 1st operating year which yields a value of €4.79 million and suggests that the deferral option value is higher than the value of investing immediately. Creating a shortened outcome or a shortcut investment in the NPV analysis will be negative in the first year, a situation not so surprising for such a significant investment. Thus, the project can be postponed until more favourable investment conditions appear.

Since investment decisions are subject to opportunity costs in regards to deferring, the investment should be made only when its NPV is higher than the value of the option. This result is so because an immediate investment implies a loss of opportunity to invest later and corresponds to the value of delaying the option. Even though the value generated by the scrubber project cannot make up for the total cost of investment, it would be sufficient to cover the deferral option. If these assumptions are applied to a binomial tree, the decision tree of current investment will signal to ‘‘invest’’ or ‘‘delay’’, at each node, which simplifies the decision-making processes for managers. The advantage of using the binomial tree for a case like this is that the result will show if the option of investing now is better when the underlying asset reaches a higher value. If the underlying asset has a lower value, then the option of postponing the project for the next period would be a better choice.

Thus, the investor will only invest if the evaluation of bunker fuel remuneration exceeds the investment initial cost together with the opportunity costs of not postponing the project for one year ahead. Since the project presents a low static NPV in the first year (despite its positive outcome over the years), it will be necessary to invest €5.68 million in implementing the scrubber project immediately or facing an increase of value in the daily ship fuel consumption. This action will risk a decrease in the cash flow as well as a decrease in the cost of the underlying asset. For example, after 4 years and 15 years, the investor will obtain future cash flows of €8.35 million and €363.42 million respectively, according to the lattice values. Having this amount of underlying asset value is a motivation for the investor to invest because the value compares to the option value is positive. Whereas at a pessimistic scenario of making future cash flows of €1.27 million and €29 102, the underlying asset value confirms that a risk avoidance will be a better option. On the other hand, a negative option price will be a signal not to take the risk of investment. This way, even with a positive NPV static the tree shows that the project should be postponed because the value of the deferral option is superior.

Next, using the approach outlined in the Equations 5, 6 and 7, the Black-Scholes option valuation model was used to calculate the real call-option value by specifying the required parameters to set-up the Black & Scholes model (1973), which are the same as in binomial option-pricing model: i.e. the initial cash flows, the volatility of the project, etc. (see Table 2). Herewith, once the inputs parameters required for setting up the model are identified, then the call-option value is calculated using Equations 5, 6 and 7. Results are as follows (Table 4):

Table 4. Values obtained with the Black & Scholes model

Input parameters	Value
d1	1.51
d2	0.29
Value of the call option: C	2 366 992.83 €

Source: Computed and constructed by authors

The results display the value of the real option (C) and the deviations from the expected value of the normal

distribution (d1 and d2) by applying the Black-Scholes model. As described above, the estimated value of the real option (ROV) in $t = 1$ by Black & Scholes option is positive and approximately amounts to €2.37 million, which does not imply that this project may be accepted and undertaken immediately. Realistically, this suggests that the investor should hold the option of this project investment and retard the investment, but not abandon the project. It also indicates the implicit value of taking the flexibility and the option into account. The large size of this value can be explained by the high volatility of the project’s cash flows (31.44%) and the significant long lifetime of the option (15 years). Note, that this situation is not surprising for such a significant investment. Similarly, to the binomial model, the option value of delay is measured by adding the ROV amount to the project’s NPV of the first-year leaves us with the extended strategic NPV equalling: $-2.43+2.37=€4.80$ million, which suggests that the deferral option value is substantially higher than the investment. Thus, in this case, also, the implication is that the investor would postpone the full project program and decide to operate it in next coming periods until better investment conditions appear. In all, the authors found the results provided by Black & Scholes formula converge to those provided by the binomial option-pricing approach, under certain assumptions.

4.3. Monte Carlo Simulation and further investigations

In this subsection, the stochastic Monte Carlo simulation is developed for the analysis of the NPV, for the investment analysis. Hence, in Table 5 below, the project scope and the inputs parameters that lead to implementing the stochastic simulation of the project valuation is defined and identified.

Table 5. Parameter used in calibration of Monte Carlo Simulation

Inputs parameters	Value	
Initial NPV _{15y.} (S_0)	€25.24	Million
Volatility (σ)	31.44	Percent
Drift (μ)	[0–1]	Random number
Trials	1000	Iterations

Source: Computed by authors

Using the approach outlined in the Equation 5 with a normal distribution, thousand unique iterations of the Monte Carlo simulation is conducted to obtain randomly the possible project values and generate a sample of the NPVs of the asset valuation paths. The most important assumption underlying this Monte Carlo model is that the generated variables (i.e. NPVs) are independent. The primary outputs of the Monte Carlo simulation, the parameters and the main descriptive statistics of the NPV of the project over the whole investment period, are presented as follows in Table 6.

Table 6. Summary statistics and Risk analysis for the simulated NPV of the Monte Carlo Simulation

Inputs parameters	Value	
Average	€14.97	Million
Median	€14.78	Million
Standard Deviation	€5.02	Volatility, Million
Min	€0.90	Million
Max	€29.67	Million
Asymmetry	0.12	Skewness
Flattening	-0.28	Kurtosis
VaR ^{1%}	€4.58	Parametric Value-at-Risk at 1% quantile, Million.
VaR ^{10%}	€8.47	Parametric Value-at-Risk at 10% quantile, Million.

Source: Computed by authors

Table 6 displays the primary outputs of the Monte Carlo simulation and presents descriptive statistics and

characteristics for the distribution of the one thousand estimated NPV iterations. Overall, within these data, the average (median) NPV is €14.97 million (€14.78 million), which is slightly lower than the estimated NPV in the project analysis that equals to €22.76 million over the whole 15-years lifespan. Dispersion in this NPV is relatively low with a standard deviation of €5.02 million, which is strongly reliant on fuel prices volatility. Across these data, an interesting result is that the NPV is simulated plausibly positive in all the experiments. Therefore, looking at the minimum and maximum values, results of the Monte Carlo iterations reveal a positive minimum value (€0.90 million), thus ranging the NPVs from €0.90 million to €29.67 million (maximum value). Moreover, aforementioned, the asymmetry (skewness) is 0.12, which shows a slightly expanded distribution to the right; and the flattening (kurtosis) stands at -0.28, indicating a slight flattening compared to a normal distribution.

Therefore, these empirical results and the absolute positive value of the simulated NPVs give support to the previous findings, implying that the project will deliver an acceptable NPV and so the relevance of undertaking scrubber technology.

Based on data obtained, the graph of the distribution of frequencies and cumulative frequencies cumulative diagram (probabilities) for the one thousand NPV iterations of the project are drawn in the following chart.

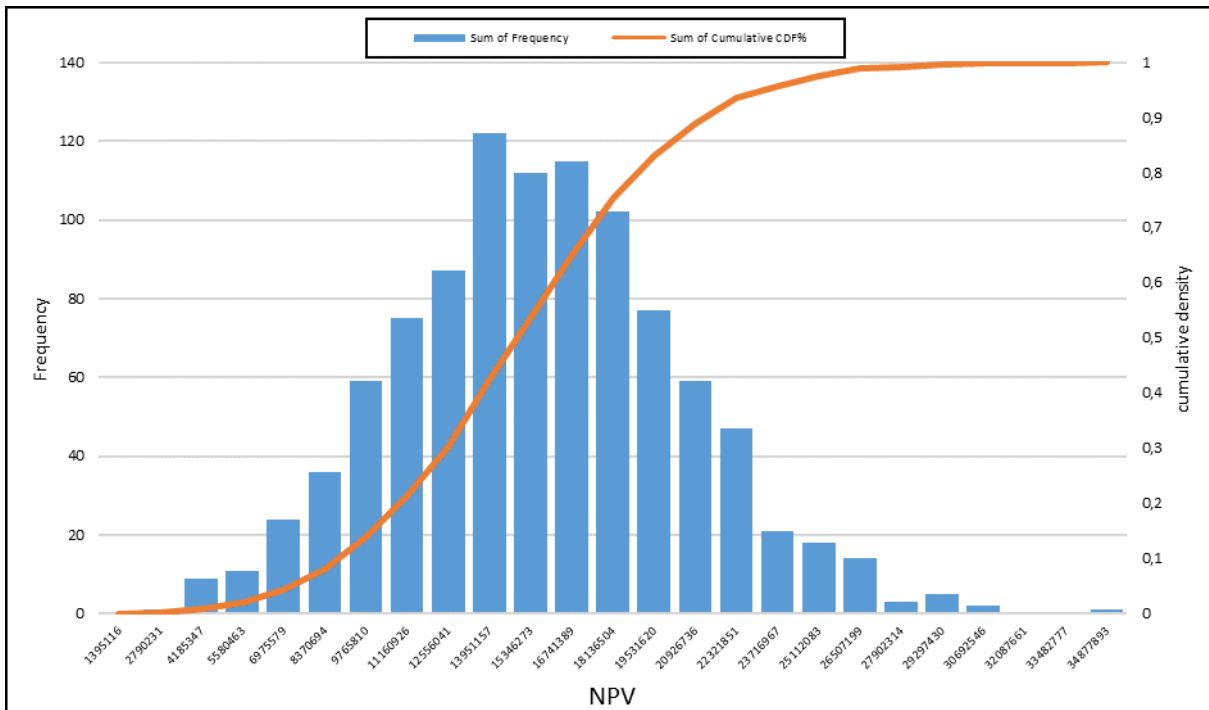


Fig.2. Probabilistic distribution of the simulated NPV_{15y}

Source: Computed by authors

Figure 2 presents the histogram of the Monte Carlo simulation results (frequencies and cumulative distribution function—CDF for the one thousand NPV experiments). As can be seen, there is strong evidence that the frequencies of the project value are normally distributed. Implications of Monte Carlo simulation drawn in Figure 2 show that 60% of the analyzed cases of the NPV are higher than €13 million. Also, it results in a probability of approximately 22% that the project value will be higher than the initially estimated project value (€22.76).

In the same stream, according to these results and the CDF, risk analysis of the Value-at-Risk indicators at 1-percent and 10-percent quantiles give interesting insights. Hence, the investors would have 99% (90%) confidence that the

project expected NPV over 15 years will generate at least an amount of €4.58 million (€8.47 million).

To address the nexus between NPV and ROV for the results obtained from the MCS, the authors process primarily by evaluation the option value (discounted by the risk-free rate) for each iteration and then calculate the average ROV of these one hundred iterations. Simulation results show that the average value of the real-option in the 1st operating year is positive and approximately equals to €1.79 million. Additionally, the option value of delay is computed as the difference between the ROV and NPV (i.e. the value-added) which amounts to a value of €4.22 million. This also supports previous findings; hence, the investor will face the decision to accept the option of the project investment, but with postponing the full project program until better investment conditions appear.

Not surprisingly, the parallel Monte Carlo simulation results, with the same input data of an option traded at 31.44% and 1000 random trials, present very similar findings to those obtained with the binomial approach and the Black & Scholes model. These results are by and large in line and consistent with the main findings of the other approaches on real options analysis.

4.4. Discussion

Under the same procedure and assumptions, results had given comparative option values at the first operating year. This gives a perception that the value of the introduction of a new scrubber investment is approximately the value provided by the binomial option-pricing model, the Black & Scholes option valuation model or the Monte Carlo method. Overall, throughout the analyses, the results are reliable and robust to various methodologies and they are not driven by any specific specification.

In contrast, when comparing the binomial results in the first year with the results of Black and Scholes, a small difference appears as shown below in Tables 7, where the three different approaches are compared with the conventional NPV calculation for the first operating year. These first-year results give useful insights to the investors when they gauge the project investment. They also allow them to decide about the best investment timing, i.e. either to launch it *today* or to postpone it for the next following year; to acquire enough guarantee about the uncertainty of the fuel market conditions and the inherently unstable nature and risks of the industry than *today*. Therefore, certainty and visibility are the essences for an investor. Subsequently, with less volatility of the market condition and a clear vision of the industry, the investor/stakeholders can generally decide easier to whether the investment is profitable in term of value creation and in line with the new regulation, or not; and the whether the payback period is satisfying or not. Thus, in presence of good economic conditions such as fewer volatility pressures or low-interest rates, there is no point to decline or postpone the investment.

Table 7. ROA Comparison between, Binomial, Black-Scholes and Monte Carlo approaches

Method of option-pricing	NPV of the 1 st -year investment	ROV for the 1 st -year of investment	Value added (Difference between ROV and NPV)
Binominal	- 2 432 655.33	2353753.78	4 786 409.12
Black-Scholes	- 2 432 655.33	2366992.83	4 799 648.17
Monte-Carlo	- 2 432 655.33	1789960.35	4 222 615.68

Source: Computed by authors

Although these option-pricing methods provide similar insights, prior studies have provided some criticisms. Hence, to benchmark our findings, previous studies in the literature (Acciaro, 2014; Glasserman, 2013) have argued that using Black & Scholes method and Monte Carlo simulation are not favourable for investment analysis, especially for the call and put option in ROA. For example, they documented that the Black & Scholes results might not provide a historical normal distribution and the Monte Carlo results are generated from simulations and random numbers, which do not follow a particular trend nor a probability distribution. To that extent, compromises can

always be made between the three different ROA pricing approaches.

Considering the setbacks mentioned, the binomial option-pricing method could be said to have an advantage over the Black & Scholes and Monte Carlo methods, as it gives flexibility of decision-making over an extended period of investment. In contrast, the other methods focus only on a specific time slot, e.g. in the last year of binomial option-pricing, the investor thereby could decide only if there are favourable conditions to invest, as far as the option to defer the project is no longer possible. In such case, the investor can only invest if the spread value of the two main fuel prices is sufficiently (or expected to) high.

Furthermore, the project value grows as the decision is postponed, due to the implied uncertainty reductions. Nevertheless, the option to defer in the binomial case might involve losses in cash flows and competition. Thus, the decision whether the project will be implemented or not can only be made if these losses are taken into account in the final decision. This suggests that although the conventional investment method does not consider this flexibility, which underestimates the project value, the incorporation of ROA alongside NPV evaluation increases the project estimation accuracy because it gives room for a project deferral. Indeed, over the full investment period, our insights of the conventional investment evaluation indicators (Panel B of Table 1) and the MCS simulated outputs (Table 6) suggest that the project presents a good investment opportunity over a long-term run.

Finally, the ROA approach allows the investor to define the best investment opportunity and decisions with the highest return for regulation compliance. The results indicate that the best short or long-term investment and capital budgeting strategies for the future of maritime companies with significant value can be considered at the early stages of a new ship investment or scrubbers retrofit device for older ships. By assessing different scenarios of the scrubber investment, the ship owners can maximise the benefit of their asset.

Conclusion

The objective of this work was to validate methods that can solve investors' challenges of SECA compliance investment decisions to avoid loss and maximise profit using the scrubber abatement technology. The results validate a stochastic approach for assessing real options with a case study for compliance with sulphur regulations. From the analysis made, the application of ROA, in particular, the Binomial approach looks promising. Given this result, a potential investor has the flexibility to re-evaluate the scrubber project and redefine a new strategy if need be.

Getting similar results although slightly different by few points between ROA between the Binomial, Black & Scholes and Monte Carlo models demonstrates that the real options approaches are practical for simulating various investment scenarios with the different situation of future oil prices. This paper contribution is new to the maritime industry that is highly characterised by burdensome uncertainties because it integrated the valuation of the payback period and discounted cash flow of the low sulphur fuel like the MGO versus the scrubber technology option as a popular solution. The findings prove that the Real-Option approach as an investment evaluation method could be a reliable and worthy approach. Investors in the maritime industry can thus rely on and take advantages of this method. The obtained results bear critical policy implications for the industry operators, the regulators of the SBR, and the IMO.

Further work will be directed towards benching marking these results with LNG driven ships. This will create a more precise picture regarding compliance investments and reduce investment decision risks.

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