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Investing in marine scrubber under uncertainty with real option thinking

Abstract

Scrubber technology is one of the valid alternatives to comply with the tightening sulphur regulation. Due to the high uncertainty associated with the oil price and shipping market, making decision about whether and when to invest in marine scrubber is very difficult. In contrast to the previous works that examine the economic feasibility of scrubber retrofitting through the net present value rule, this paper applies the Real Option Analysis to find the optimal investment strategies. The proposed decision-making framework addresses the uncertainty and the value of deferral option embedded in the scrubber investment. The multiple sources of investment uncertainties are explicitly analyzed and integrated in the modeling by using Rainbow option. The results demonstrate that the value of the scrubber investment has significantly increased for several cases by considering the deferral option. It is thus important for ship owners to consider the available options before proceeding with abandoning or investing strategy. The proposed framework can be widely applied to other ship retrofitting investment evaluations, which include similar investment alternatives and uncertainties.

Keywords: Real Options, Scrubber Technology, Deferral Option, Rainbow Option, Flexibility, Uncertainty

1. Introduction

With the tightening regulation of preventing air pollution from ships, shipping industry is prompted to develop greener ways of shipping. It may involve innovative design of new ships, retrofitting of existing fleets with new components, or upgrading the operational standards. How to comply with these emission regulations will have great implications on ship owners and managers. In most cases, compliance came at a cost and ship owners ultimately pay the environmental invoice.

As far as the fuel sulphur limits is concerned, shipping companies need to make some key investment decisions: should it opt for low sulphur fuels, should it install exhaust gas scrubber systems on their ships, or should it invest in LNG fuels. According to a recent survey by Lloyd's List (2015), 57% of the respondents find scrubber the best-suited solution[1] to meet the challenge of reducing SOx emissions. Compared to the 19% figures from 2014, we see a significant increase in the acceptance level of selecting the scrubber, because of more successful instalment by ship owners, better guarantees offered by scrubber makers and increased certainty over operational regulations (Lloyd's List, 2014). However, the sale of marine scrubbers has been hit since the end of 2014 due to the plunging oil prices. A reduction in cost saving associated by using cheaper Heavy Fuel Oil made scrubber less attractive to a ship owner, let alone its complexity added to the ship operation.

But know that oil price has always been volatile. Retrofitting ships with scrubbers is economically very interesting in periods of high oil prices, and rather dull when the oil price is depressed. One big questions is 'is the scrubber a valid option given the uncertainty about future oil prices and if so when would be the optimal time for scrubber investment?'

A traditional tool for aiding investment decision is Net Present Value (NPV), which has been widely applied in various disciplines. However, NPV reflects a static value derived from assumptions that only consider a single scenario, which may differ substantially from the realized cash flows. Choice based on NPV is either a now or never investment decision and it does not allow the management to modify a decision in the future opportunities.

The objective of this study is to provide a Real-Options-based framework for strategic investment in marine scrubber systems. Real Options Analysis (ROA) enables the flexibility of decision-making to incorporate the uncertainty and risk (Dixit & Pindyck, 1994). We are particularly interested in one type of options, namely the option to wait and defer investment for a particular time period. The main contribution of this study is two-fold. First, this study provides evidence for the applicability of Real Options Analysis to investment decision of scrubber technology. We highlight the hidden value of flexibility to wait for investment. The proposed framework is generic enough to be applied to other ship retrofitting investment evaluations, which include similar investment alternatives and uncertainties. The implication of this study will also benefit a wider business context, including marine equipment suppliers, ship charterers and banks. Second, we extend the scrubber investment studies by adopting Rainbow Option approach that allows for the multiple sources of uncertainties in estimation, namely the uncertainties of two oil price spread and shipping market condition. The nature of rainbow option reveals the true value of deferral options embedded in scrubber investment.

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[1] The choice is followed by low sulphur fuel oil (44%) and LNG (20%). The respondents in the survey includes shipowners or other bodies responsible for commercial operations of vessels, charterers, technology companies or developers, regulatory bodies, industry associations or other interested parties (Lloyd's List, 2015).

The paper is organized as follows. Section 2 compares the traditional NPV and Real options analysis, and outlines the application of ROA in shipping. Section 3 presents the ship data for case study and the estimation of static net present value. The details of real option analysis are presented in Section 4 and the main results are discussed in Section 5. Section 6 provides the conclusion and direction for future study.

2. Literature review

As Dixit and Pindyck (1994) discussed in their influential book, most investment decisions share three important characteristics. First, the investment is partially or completely irreversible. Second, there is uncertainty over the future payoffs from the investment. Third, you have some ability to delay your timing of investment to get more information (but never complete certainty) about the future. The interaction of these three characteristics in varying degrees determines the optimal decisions of investors.

A traditional tool for evaluating investment opportunities is the net present value analysis. It is based on discounted cash flow techniques, which first calculates the present value of the expected profits and costs of the investment and then sees whether the differences between the two is greater than zero. If NPV is positive, the investment should be accepted, while a negative NPV means a loss and the investment should be rejected (Prasad & Papudesu, 2006). NPV method is quite simple and straightforward, and has become a popular investment criterion since the 1950s, and is still widely used today.

However, the investment decision is not only determined by having a positive or negative NPV number, the investor should also decide when it is optimal to make the investment. For instance, a project currently has a negative NPV but has the opportunity to expand greatly in a few years' time. Therefore, instead of making a 'now or never' investment decision under uncertainty, management can wait and gather new information to reduce the uncertainty about the future cash flow (Hopp & Stavros, 2004). Such flexibility is particularly valuable considering the irreversible investment expenditures and great economic uncertainty, which is not captured by the traditional NPV method.

Real Options Analysis supplements the NPV approach by addressing the uncertainty and value of flexibility. It allows for modifying a decision when new information becomes available, such as deferring, expanding, contracting, or abandoning an investment at a predetermined cost (exercise or strike price) on or before a predetermined date (Dixit & Pindyck, 1994). Managers' options to take actions that affect real investment projects are comparable to options on the sale or purchase of financial assets. A real option is a right, but not the obligation to take an action. Thus, the choice is optimum not only at the time of making the investment decision, but also in respect of future options available (Prasad & Papudesu, 2006).

The value that ROA brings to project valuation made it quickly being adopted by various industries, including aerospace, automotive, chemicals, oil and gas and so on (Prasad & Papudesu, 2006). Shipping also face considerable profit uncertainty, as well as substantial investment costs, which makes it natural to apply real options for investment evaluation in shipping. The earlier application is in the seminal PhD thesis of Goncalves (1992) who developed a model for the determination of optimal chartering and ship investment policies for bulk shipping. Given the considerable profit uncertainty for the oil tanker market, Dixit and Pindyck (1994 and 2004) applied their real option model on entry, exit, lay-up and scrapping decisions in the tanker industry. While previous studies mostly focuses on the deferral option, Tsolakis and Hopp (2004) provided a wider real option framework for a ship owner, which also includes the option to choose the best operating strategy and the option to vary the mix of output. Investment on ships has been further studied by Bendall and Stenn (2003, 2005 and 2007), Dikos (2008) and Sødal et al. (2008). In recent years, ship owners in recent years have also been challenged by investing in emission abatement technologies to comply the IMO regulation. Several studies have been conducted to estimate the economic feasibility of ship emission abatement technologies, for instance Møllenbach et al. (2012), Jiang et al. (2014), Schinas and Sefanakos (2014), Boer and Hoen (2015), Panasiuk and Turkina (2015), Hansen et al. (2016) among others. Yet, decision criterion is mostly based on NPV or payback time. Very few studies have applied the Real Options Approach in green shipping investment. One of these few studies is Acciaro (2014), which evaluated the investment in LNG retrofit for ECA compliance with an aggregated uncertainty factor.

3. The case study context

3.1. Ship data

In this study, the scrubber investment is assessed against the alternatives of operating the ship on low sulphur marine gas oil by using ROA. Scrubber costs, fuel consumption and operational profile are considered on a vessel-specific basis. We choose the reference vessel (MS Nord Butterfly, product tanker, 38,500DWT) from the ECA retrofit study by Green Ship of the Future (Møllenbach, 2012). The number of operational days per year at sea and in port based on a certain ECA percentage and service speed is shown in Table 1. It should be noted that the number of days based on a service speed of 14 knots and 50% ECA percentage is directly collected from the ECA study report, while other numbers are calculated by authors. It is also assumed that days at port for idling and unloading will only be affected by the service speed, and would not change according to the variation of ECA percentage expect for the case of 100% ECA exposure. Ship particulars can be found in Appendix 1.

Table 1 Days of ship operation at sea, in port idling and port unloading

		14 knots				**12 knots**				**10 knots**		
		Non-ECA	ECA	Total		Non-ECA	ECA	Total		Non-ECA	ECA	Total
	sea	165.0	55.0	220.0	sea	174.9	58.3	233.2	sea	186.1	62.0	248.2
25%	idling	57.5	57.5	115.0	idling	52.3	52.3	104.5	idling	46.3	46.3	92.6
	unloading	15.0	15.0	30.0	unloading	13.6	13.6	27.3	unloading	12.1	12.1	24.2
		Non-ECA	ECA	Total		Non-ECA	ECA	Total		Non-ECA	ECA	Total
	sea	110.0	110.0	220.0	sea	116.6	116.6	233.2	sea	124.1	124.1	248.2
50%	idling	57.5	57.5	115.0	idling	52.3	52.3	104.5	idling	46.3	46.3	92.6
	unloading	15.0	15.0	30.0	unloading	13.6	13.6	27.3	unloading	12.1	12.1	24.2
		Non-ECA	ECA	Total		Non-ECA	ECA	Total		Non-ECA	ECA	Total
	sea	55.0	165.0	220.0	sea	58.3	174.9	233.2	sea	62.0	186.1	248.2
75%	idling	57.5	57.5	115.0	idling	52.3	52.3	104.5	idling	46.3	46.3	92.6
	unloading	15.0	15.0	30.0	unloading	13.6	13.6	27.3	unloading	12.1	12.1	24.2
		Non-ECA	ECA	Total		Non-ECA	ECA	Total		Non-ECA	ECA	Total
	sea	0.0	220.0	220.0	sea	0.0	233.2	233.2	sea	0.0	248.2	248.2
100 %	idling	0.0	115.0	115.0	idling	0.0	104.5	104.5	idling	0.0	92.7	92.6
	unloading	0.0	30.0	30.0	unloading	0.0	27.3	27.3	unloading	0.0	24.2	24.2

Source: authors

3.2. The static net present value

To provide a basis for real options analysis, we first estimate the cost and benefit of scrubber installation through the static Net Present Value (NPV). When ship is retrofitted with scrubber, it does not comprise any direct economic benefit. Instead, it is a matter of putting the capital costs of the equipment and operational costs against the financial benefits of being able to use cheaper fuels. Capital costs are all initial costs related to scrubber equipment and installation. Operating costs are the direct yearly costs of operating the scrubber, including the cost of caustic soda, slurry disposal and maintenance (Boer & Hoen, 2015). The financial benefit depends on the price difference between Marine Gas Oil (MGO) and Heavy Fuel Oil (HFO), as well as the amount of fuel consumption. Therefore, the static net present value of scrubber technology is given by:

$$NPV_{v,s,\alpha} = \sum_{t=1}^{T} \frac{\left(F_{v,s,\alpha}^{MGO} \times P^{MGO} - F_{v,s,\alpha}^{HFO} \times P^{HFO}\right) - OPEX_{v,s,\alpha}}{(1+r)^t} - CAPEX_v$$

where

$NPV_{v,s,\alpha}$ is the net present value for vessel v sailing at speed s with α ECA percentage, measured in US dollars;

$F_{v,s,\alpha}^{MGO}$ and $F_{v,s,\alpha}^{HFO}$ are fuel consumptions of MGO and HFO for vessel v operating with speed s and α ECA percentage, measured in ton

P^{MGO} and P^{HFO} are fuel price of MGO and HFO, measured in US dollars per ton,

$OPEX_{v,s,\alpha}$ is the operating costs of scrubber for the vessel with aforementioned operation profile, measured in dollars per kwh main engine

$CAPEX_v$ is the capital investment costs of scrubber for vessel v, measured in US dollars per kw main engine.

T is the minimum of scrubber equipment lifespan and the remaining lifespan of vessel v.

r is the risk-adjusted discount rate.

The fuel consumption is closely related to the service speed, as well as vessel's operation stages (see Appendix 2). There will be an additional fuel consumption of the auxiliary engines for the operation of scrubber system. The average daily fuel consumption of the auxiliary engines (AE) during harbour idling and unloading is based on the ECA study. The daily fuel consumption of main and auxiliary engines during free sailing is obtained from the emission and oil consumption model developed by Kristensen (2012). This model considers main ship particulars, engine type, operation conditions and emission reduction technologies. When a scrubber is installed or HFO is switched to MGO, the amount of oil consumption will change accordingly (Jiang et al., 2014).

Fuel price in this study is collected at January 2016, corresponding to 125.9 US dollars per ton for HFO and 272.3 US dollars per ton for MGO (Clarkson SIN, 2016). The CAPEX and OPEX of scrubber are estimated based on the unit cost figures collected from the study of DMA (2012), where the unit OPEX is 0.0025 Euro per kwh (main engine) and the unit CAPEX is 150 Euro per kw (main engine) for investment and 225 Euro per kw (main engine) for installation. The reference vessel was built in 2008 with roughly 17 years remaining lifespan and the average scrubber equipment for retrofit can last for 12 years.

Thus T is 12. A risk-adjusted discount rate of 9% is used. The static net present value of each scenario is presented in Table 2.

Table 2 The static net present values

ECA% \ Speed	14 knots	12 knots	10 knots
25%	(3,370,849)	(3,882,886)	(4,222,592)
50%	(819,367)	(2,472,325)	(3,557,865)
75%	1,288,753	(1,159,355)	(2,760,885)
100%	4,089,124	783,207	(1,387,873)

Figures in the brackets are negative values. Source: author's estimation.

For most of the scenarios, the cost saving cannot even cover the investment, leading to negative net present values. It suggests that the scrubber should not be installed particularly when the vessel sails at a slow speed with a smaller ECA percentage. However, the above estimation is based on assumptions, and changes in parameters can significantly affect the expected cash flows of the project. In the face of great uncertainties, the Real Option Analysis will be made to estimate the value of deferral option, before a firm decides to commit or abandon the investment.

4. Real option analysis

4.1. Deferral option

In the face of key investment uncertainties, ship owners could postpone the investment. If we make the assumption that the investor has a finite horizon to decide to invest, then this date in the future, say L, is the expiration date of the 'option'. Note that since the investor can decide to invest any time between his initial time t and the expiration date L, this option is equivalent to an American call option (Goncalves, 1992). According to the possible global sulphur cap in 2020, we assume that ship owners can defer their investment of scrubber for up to four years in order to resolve the uncertainty.

A binomial tree is used to estimate the evolution of underlying asset value (here refers to the value of scrubber retrofitting project) in equidistant intervals over the life of the option. In the first interval step, the initial asset value either goes up by u factor or down by d factor and continue goes up by u factor or down by d factor from there. Thus, the value of underlying asset value at time t for decision node N_{tij} can be calculated as:

$$S_{tij} = S_0 \cdot u^i \cdot d^j$$

$$i + j = t, \quad t = 0,1, \dots, L$$

where S_0 is the present value of the future cash flows that the scrubber investment will generate over the time L. It is a net cash flow as calculated by the static net present value. The future oil prices can be obtained via Monte Carlo simulation. u is the up factor denoted by

$$u = \exp\,(\sigma \cdot \sqrt{\delta_t})$$

and d is the down factor denoted by

$$d = 1/u$$

where σ is the volatility factor, which will be discussed in details later; δ_t is the time associated with each time step of the binomial tree. Then, the option value at N_{tij} is the maximization of investing at that point or waiting until the next time period before the option expires (Prasad & Papudesu, 2006), denoted by

$$O_{tij} = \max(I_{tij}, W_{tij})$$

The value to invest at N_{tij} is calculated as the expected asset value minus the exercise price X_t at time t when exercising the option, denoted by

$$I_{tij} = S_{tij} - X_t$$

For simplicity, we assume that X_t will not change during the option life. The value to wait until the next time period, in other words for keeping the option open, is the weighted average of potential future option values using the risk-neutral probability p, denoted by

$$W_{tij} = \begin{cases} \left[p \cdot O_{tij} \cdot u + (1-p) \cdot O_{tij} \cdot d\right] \cdot \exp(-r\delta_t) & if\ t + \delta_t < \mathrm{L} \\ 0 & if\ t + \delta_t = \mathrm{L} \end{cases}$$

where r is the risk-free interest rate. The optimized future decision at node N_{tij} is then made and O_{tij} can be folded back in a backward recursive fashion into the current value to support the optimal solution for today.

4.2. Estimation of volatility factors

A key input parameter of any ROA is the volatility factor that represents the uncertainty associated with the underlying asset. We use Monte Carlo Simulation to calculate cash flow profiles over the scrubber lifespan and the volatility factor (σ) is computed by using the logarithmic cash flow returns method. This is an aggregated volatility factor (σ), which combines all uncertainties that drive the payoff of scrubber investment.

However, the price difference between MGO and HFO, has the most important role on the scrubber payoffs and option values, it would be interesting to keep the uncertainty contributed by oil price (σ_1) separate in the options calculation. Additionally, the poor financial state of the shipping industry presents another dimension of uncertainty. For instance, ship owners may be forced to laid up, sell, or scrap their ships, if freight rate is not significantly recovered or even falls below the operating costs. If so, vessels retrofitted with scrubber systems have to face with considerable sunk costs. On the other hand, ship owners may have more incentives to install the scrubber in booming market, during which more bunker costs will be saved because of the possible higher service speed and increased turnovers. Therefore, the uncertainty of shipping market condition (σ_2) should also be treated separately.

In fact, separate treatment of different sources of uncertainty provides a better estimation of option value embedded in the project. It also makes it easier to re-evaluate the project value when one source of uncertainty changes or clears (Prasad & Papudesu, 2006). In our model, we have computed the volatility factor (σ_1) by using historical data (January 1990 to January 2016) for heavy fuel oil and marine gas oil collected from Clarkson. Historical BCTI was used to calculate the volatility factor (σ_2). Both volatility factors are based on monthly historical data and then converted to yearly volatility factors by multiplying the square root of 12 (Prasad & Papudesu, 2006). All volatility factors (σ, σ_1, σ_2) are assumed to be constant during the life of the option.

The possible postpone of global sulphur cap to 2025 is another uncertainty surrounding the scrubber investment. The decision is subject to the results of a fuel availability study to be completed before the end of 2018 (Lloyd's List, 2015). It is worth noting that European Union (EU) has already agreed that the 0.5% sulphur cap will apply to all EU Member States within 200 miles of the coast from 2020, regardless of IMO decision on postpone the global cap until 2025. Given our case study mainly focus on the trip within EU, this uncertainty is not considered.

4.3. Rainbow option

When multiple sources of uncertainty is considered, the option is called rainbow option. The solution is basically the same as for a single volatility factor in deferral option except that it involves a quadrinomial tree instead of a binomial tree.

Strictly speaking, the quadrinomial lattice is appropriate when the uncertainty factors are independent of each other. In our case, the correlation between fuel oil spread (MGO-HFO) and BCTI is 0.254, which is not significant and thus it should be appropriate to apply the quadrinomial method. For the sake of simplicity, the time increment is 2 years in the rainbow option while still keeping option life as 4 years. The two volatility factors will yield two up and down factors, as well as two risk-neutral probabilities. As a result, the joint-up and -down factors are u_1u_2, u_1d_2, d_1u_2, d_1d_2, determining the possible asset value in the next time period (Prasad & Papudesu, 2006).

5. Results and discussion

5.1 results of rainbow option analysis

The CAPEX of scrubber investment for this case study is $4,026,896. Four years' option life is divided into two time intervals. The annual volatility factor of oil price spread is 43.12% and 38.51% for BCTI. Risk-free interest rate is 5%. The present value of future cash flows associated with scrubber investment is calculated for each operation scenario, which can be found below in Table 3.

Table 3 The present value of future cash flows for scrubber system ($)

PV	14	12	10
25%	656,048	144,010	-195,696
50%	1,914,020	927,655	279,884
75%	3,171,992	1,711,140	755,463
100%	4,843,049	2,870,319	1,574,777

Source: author's estimation.

Applying the rainbow option analysis for all operation scenarios, and the values of deferral option are summarized in Table 4. All option values are positive and vary significantly from zero to $3,512,602 and the results can be categorized into four groups.

In the first group, the static NPV is highly positive and even greater than the option value to wait. Thus, there is no point to wait and the firm can make the investment now. The next two groups show a low negative or positive NPV with positive option values. For these cases, it may pay to wait for one or two years and make the optimal investment later. Vessel in these groups have either higher ECA percentage or faster service speed. For instance, when the vessel operates at14 knots and 50% ECA percentage, the NPV is -$819,367 and the option value to wait is $821,405. This means that the value of the project has increased $1,640,772 by considering the deferral option. Although the option valuation does not alter the decision not to invest at this time, it does provide the management with significant flexibility instead of abandoning the investment now. If the future market were favourable, the company could move forward with full investment or even scale it up to more ships, thus taking advantage of the upside potential of the investment. On the other hand, in the case of unfavourable results, you may let the option expire and abandon the idea of investing a scrubber, thereby limiting your losses to the minimum. The net present values of the third group are usually very negative. In the meanwhile, the value of deferral option is not high compared to the first two groups, indicating that the management could postpone the investment in the long term. For the last group, a combination of highly negative NPVs and zero option values suggest that the investment may not be worth in the end.

Table 4 The values of deferral option and investment decisions

Group	Operation profile	Static NPV	Option value	Criterion	Investment decision
I	14 knots, 100%	4,089,124	3,512,602	NPV>>0, ROV>0, NPV>ROV	Invest now
II	14 knots, 75%	1,288,753	1,873,121	NPV>0, ROV>0, NPV<ROV	Wait to invest
	12 knots, 100%	783,207	1,620,910		
	14 knots, 50%	(819,367)	821,405	NPV<0, ROV>0, NPV<ROV	Wait to invest
	12 knots, 75%	(1,159,355)	651,789		
	10 knots, 100%	(1,387,873)	537,784		
III	14 knots, 25%	(3,370,849)	83,402	NPV<<0, ROV>0, NPV<ROV	Delay investment as long as possible
	12 knots, 50%	(2,472,325)	171,903		
	10 knots, 75%	(2,760,885)	115,796		
IV	12 knots, 25%	(3,882,886)	0.00	NPV<<0, ROV=0, NPV<ROV	Possibly never invest
	10 knots, 50%	(3,557,865)	0.00		
	10 knots, 25%	(4,222,592)	0.00		

Figures in the brackets are negative values. Source: author's estimation.

If the investment project has a very high or low NPV, the additional value provided by real options would most likely be so negligible that the investment decision would still be a 'go' or 'no go'. If the NPV is close to zero (either positive or negative), the option to wait has the utmost benefit. Because option values are always nonnegative, the static NPV can lead to an under-evaluation of investment projects. If we say DCF provides a fixed path for investment, then ROA offers an expanded net present value and strategic maps of contingent decisions that related to future uncertainties (Prasad & Papudesu, 2006).

6. Conclusion

This paper applies the Real Options Analysis to the investment decision-making of marine scrubber, which is one of the abatement technologies to comply with the regulation concerning fuel sulphur limits. Using data from a real ship, we address the key question about whether and when to retrofit the ship with the scrubber system. We seek the optimal investment decision by extending the static net present value with the value of a deferral option to exploit upside profits and limit downside losses. Taking into account the multiple sources of uncertainty, Rainbow option has been adopted to control the uncertainties of oil price spread and shipping market condition. Given various vessel operation profiles, the results show the importance of making investment decision with real option thinking. In particularly, for those operation scenarios with low negative or positive net present values, the value of the project significantly increased by considering the deferral option. It also provides the implication on the timing of an investment. One limitation of this study is that the uncertainty only focuses on the market-related factors, while private uncertainty such as the technically feasibility is not taken into consideration. For the future study, it would be interesting to exam other types of option embedded in the scrubber investment. For example, to mitigate the performance uncertainty of the scrubber system, the company may first install the scrubber in one vessel and afterwards expanded the investment to the rest of the fleet if the investment is profitable.

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Appendix

Appendix 1 Reference ship particulars and engine data

MS Nord Butterfly (Product tanker)	
Length (LOA)	182.86 m
Length PP (LPP)	174.50 m
Breadth (Bmld)	27.40 m
Depth (Dmld)	16.80 m
Draft (Design)	9.55 m
Draft (Scantling)	11.60 m
Deadweight (Design)	29,000 dwt
Deadweight (Scantling)	38,500 dwt
Main Engine	6S50MC-C7.1 model, MAN B&W
Specified Maximum Continous Rating (SMCR), at 127 rpm[2]	9,480 kw
Normal Continous Rating (NCR), at 120.3 rpm	8,058 kw
Auxiliary Engine	3 ×6L23/30H model, MAN B&W
Normal Continous Rating (NCR), at 900rpm	960 kw and total 2880 kw

Source: Møllenbach et al. (2012)

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[2] Revolutions per minute

Appendix 2 Average fuel consumption

AE consumption, harbour idling	
HFO + scrubber	4.3 ton/day
MGO	4.1 ton/day
AE consumption, harbour unloading	
HFO + scrubber	12.7 ton/day
MGO	11.9 ton/day
ME+AE consumption at sea, 14 knots	
HFO + scrubber	25.4 ton/day
MGO	23.5 ton/day
ME+AE consumption at sea, 12 knots	
HFO + scrubber	14.9 ton/day
MGO	13.8 ton/day
ME+AE consumption at sea, 10 knots	
HFO + scrubber	8.5 ton/day
MGO	7.9 ton/day

Source: Source: Møllenbach et al. (2012) and authors