Maritime Investment Appraisal: The Case of Waste Heat Recovery Systems Installation

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Abstract. To ensure the compliant of the CO2 regulation, the IMO set standards for the Energy Efficiency Design Index (EEDI) for ships that also led to a higher propelling costs and additional abatement investments for ship owners making energy efficiency and fuel-saving a high priority in shipping operations.
This study focuses on the financial analysis of investment on waste heat recovery that has its origin in the heavy industry especially in power plants, steel mills and other high-energy fabrics. As with other industries, the waste heat recovery systems (WHRS) can also be used to reduce emissions and fuel consumption of ship engines but is still relatively new in the maritime industry and until now, the economic assessment of the installations are still not adequately covered in the scientific literature.
The evaluation of the investment of the WHRS installations on ships carried out in this work used the traditional capital budgeting analysis followed by the real-option approach that includes a fuzzy model. The results were validated using data from a ferry plying between Tallinn and Helsinki. The capital budgeting analysis reveals that the investment in maritime WHR technology is economically favorable only under certain frame conditions. On the other hand, the real-option analysis shows a practical and pragmatic assessment of the WHRS investment even when implemented under high uncertainty and volatility condition in material resource markets.

Keywords: Energy Efficiency, EEDI, Maritime Investments, Real-Options, Fuzzy models

1 Introduction

Energy-saving and emission reduction gained high importance in the shipping sector within the last years [1]. The installation of air purification technologies on ships is related to high investment costs so that effective methods for the economic assessment of such investment is necessary. Due to SECA regulations implementation, the economic evaluation of abatement technologies on ships has gone beyond the traditional and classical capital budgeting approaches to complex concepts like real options methods [2, 3]. A closer look into the experiences from the Baltic Sea region shows that those ship operators who implemented new abatement technologies had to spend more money on additional fuel consumption and at the same time deal with additional CO2 consumption for running such systems [4, 5]. This is why sophisticated energy-saving concepts are necessary to reduce fuel consumption for clean shipping technologies.

Waste heat recovery systems (WHRS) increase energy efficiency in shipping by transferring high-temperature exhaust gases to electrical energy. Studies about maritime WHRS estimate the regained energy to about 11% of the main engine power, which yields reductions in fuel consumption of the main engine to between 3% and 8% [6]. However, the WHRS is rarely used in the shipping sector [7] and scientific literature on maritime use of WHRS exists only concerning technical issues whereas economic aspects of these installations represent a neglected topic [8]. An important reason might be that traditionally the financial assessment of investment decisions uses capital budgeting methods that are not able to handle changing frame conditions but WHR installations are long-term investments that are strongly influenced by changes in fuel prices or interest rates [9] so, they require a more advanced approach in their evaluation. One possible approach is based on the real-option approach that can integrate the changes in the investment environment [10].

The paper intends to assess the economic performance of WHRS investments as maritime innovation projects for clean shipping. For the analysis of investments, the traditional capital budgeting techniques are extended to the real-options approaches. The following section gives the theoretical background of the study. The third session highlights the methodology used while the fourth session validates the work with an operational profile of a ship. The fifth session concludes the study.

2 Theoretical Background

2.1 Waste Heat Recovery Technology

Besides fuel costs, green shipping is a paramount maritime agenda of the International Maritime Organization (IMO) implying that the reduction of emissions like CO2 became pivotal to the new IMO rules for the Energy Efficiency Design Index (EEDI) made in 2013 [11]. The energy efficiency of the ship's main engines is about 50% depending on the load factor of the engine. Even though 50% of energy efficiency already represents a top value in the transport sector, ship owners further try to lower the fuel consumption since fuel sums up to 45% of the total ship running costs [12]. The remaining half of the burned fuel in the ship's main engines represents waste energy that leaves the ship as emitted exhaust gas heat through the funnel [6]. This is where the benefit of the WHRS installation becomes apparent so that the energy efficiency rises from 50% to about 55% when the ship engine combines with a WHRS. Thus, the additional benefit of a WHRS arises from the IMO EEDI formula by lowering the EEDI coefficient of the ship and at the same time reducing the CO2 emission level [13, 14]. Shu et al. explained that the exhaust gas temperature in the range of 250–500° C is high enough for the production of steam and the generation of electricity, which increases energy efficiency [15]. So far, the economic assessment of maritime WHRS has been few, however, different scholars including Shu et al., Baldi & Gabrielii, and Daccord that focused on the technical aspects also revealed costs information to calculate the investment planning that includes estimations for the payback time [15, 7, 16]. Several types of WHR technologies are available making it complicated to find unique access to the economic assessment but MAN [6] was able to differentiate between the following systems that are used on different ship types depending on the performance of the main engine described in Table 1:

Table 1. Types and characteristics of WHRS (MAN 2014)

Type	Engine power	Recovery rate	Investment costs	Maintenance cost
ST-PT	> 25,000 kW	8-11%	10 mio. US$	US$ 30,000
STG	15,000 kW – 25,000kW	4-8%	7 mio. US$	US$ 20,000
PTG	< 25,000 kW	3-5%	2 mio. US$	US$ 10,000

Behind the abbreviations of the three main types of WHRS, the used technology is embedded - An ST-PT system combines a steam turbine (ST) with a power turbine (PT) generator, a gear, and a generator unit with a single or dual pressure steam turbine. STG is a steam turbine generator that consists of a steam turbine, a gear, and a generator unit. Finally, the PTG represents a power-turbine generator unit. Generally, a steam turbine is driven by the steam of the exhaust gas boiler that heats the water to a high temperature to generate electricity. On another hand, a power turbine generates electricity directly from the exhaust gases of the main engine. An important feature of all the three types of WHRS is that they only start generating electricity when the load of the main engines works above 40 - 50% and when they are within this working range, the additional fuel consumption of ca. 1.2% is necessary to tune the WHRS. This makes the estimation of the technical as well as the economic efficiency of a WHRS complicated because the energy production depends on the operation profile of the ship, i.e. during port operations or when in low-speed areas, the load factor of the main engines works below the threshold of the WHRS [8].

A general problem in the economic assessment of maritime technologies is in the estimation of the investment costs of devices because these prices depend on special agreements with the ship owners. Concerning the investment prices for WHRS, the values range includes yard costs between US$2,000,000 and US$10,000,000 [15]. The corresponding annual maintenance costs are estimated to be US$10,000 and a combined power and steam turbine system to US$30,000 so that the expected annual maintenance costs range between US$10,000 and US$30,000 [17]. The technical interplay of the components of a WHRS on ships is described in Figure 1:

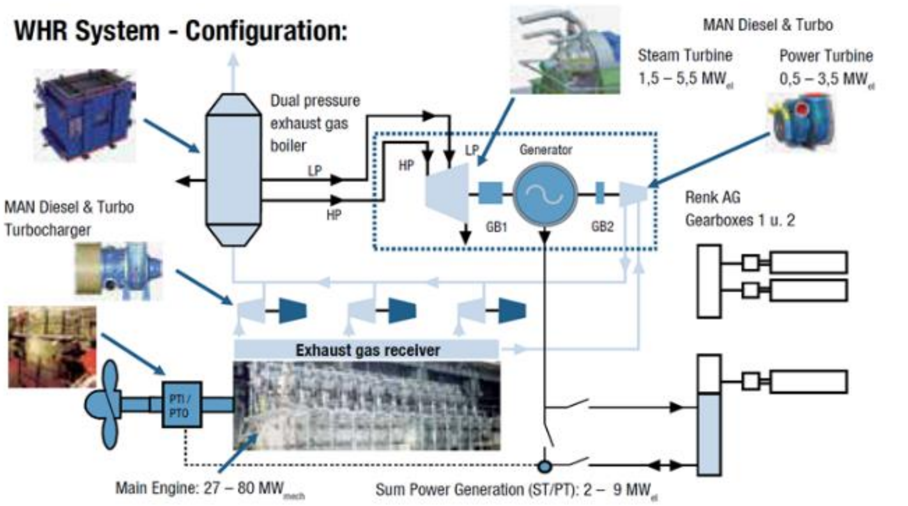

Fig. 1. The construction principle of a WHRS (MAN 2014). The economic life of a WHRS installation is considered as 20 years, which corresponds to the normal lifetime of a vessel.

2.2 Investment Appraisal

Investment appraisal usually belongs to core corporate finance professionals but in recent years, investment valuation in the maritime industry gained popularity among scholars and shipping business professionals. A classical starting point for investment assessment is the dynamic Discounted Cash Flow (DCF) valuation method that usually is subsumed under capital budgeting. More modern investment appraisals apply real options analysis, decision tree analysis, or Monte-Carlo methods. However, the DCF model is still recognized as the traditional approach that supports decision-making because it provides financial indicators comprising the net present value (NPV), the internal rate of return (IRR), and other profitability indicators. The most commonly used economic assessment indicator for projects is the NPV that considers the present value of the expected future cash flows of the project over the economic lifespan shown in equation 1:

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

Here, the CF_t is the expected cash flow in year t; T is the economic life of the investment; r is the Discount rate and $CapEx_0$ is the initial investment cost - in this case, the investment costs for the WHRS installation. In the event of a WHRS investment, the annual cash flows include the annual maintenance costs as outflowing cash flows and the annual fuel costs savings as the inflowing cash flows. Based on the NPV formula (1) it is possible to deduct further financial performance indicators like the payback period of the investment, the Internal Rate of Return (IRR), and further profitability indicators. These methods are also accepted and often applied in the shipping industry but are limited in changing frame conditions of investments such as high volatility of oil prices and changes in interest rates.

Scientific literature proposes investment appraisals based on real-option models in mining, oil, and power plants however sustainable energy investment projects as found in maritime are like experimental techniques that need appraisals that can cope with changing environmental indices. Salahor and Samis et al. [18, 19] discussed the advantages of real options evaluation methods against the DCF in cases of larger and long-term projects and highlighted them for mining and oil projects. Accario and Atari et al. [2, 3] introduced real options models for maritime investments in addition to the traditional NPV methods. They complemented the real options analysis using the Black-Scholes model, Monte-Carlo-Simulation, and Binomial option pricing to take account of changes in fuel prices and other market conditions.

Straightforwardly, the authors follow a general option-pricing model of Black-Scholes to model the investment opportunity in WHRS technology [20]. The approach is based on a call option on the NPV of the expected future fuel cost saving from the operation of a WHRS installation on a ship. Thus, by following the work of Black-Scholes, the price of such a call option can be calculated using the following formula:

$$Option\ Call\ Price\colon\ C = S_0 N(d_1) - Ke^{-rT} N(d_2) \tag{2}$$

The parameters for the value of a call option *C* are the NPV (S_0) of future cash flows from investing in WHRS, the time *T* of the option to expiration, the option's exercise price *K* at the end of the period, and the long-term interest rate *r* for financing the WHR installation.

Parameters $N(d_1)$ and $N(d_2)$ is calculated by applying the standard normal distribution $N(x)$ for the two terms d_1 and d_2 depends on the characteristics of the maritime investment that has to be calculated by the following formula:

$$d_1 = \frac{ln\left(\frac{S_0}{K_t}\right) + \left(r + \frac{\sigma^2}{2}\right) \times T}{\sigma\sqrt{T}};\ d_2 = d_1 - \sigma\sqrt{T} \tag{3}$$

Here, the parameter σ expresses the riskiness of the WHRS, i.e. the volatility of the worst- and best-case scenario of the investment in form of a calculated standard deviation of the random variable *S* describing the rate of return.

Newer methods in evaluation of investment cases combine fuzzy logic with real-option analysis for improved modeling of the uncertainties related to investment decisions. Carlsson and Fullér [21] developed a fuzzy real-option analysis (FROA) where the present values of expected cash flows and expected costs are estimated by trapezoidal fuzzy numbers. This method has been successfully applied to many investment evaluations [22].

As mentioned, the operational profile of the ship affects the daily fuel consumption, the sum of recovered energy of the WHRS, as well as the oil price level during the long lifespan of a WHRS. If these figures are available, it is possible to calculate the future cash flows together with the values for fuel cost savings.

3 Methodology

This research is based on financial models from capital budgeting and real-option theory that comprises an FROA model. The existing models are adapted to the situation of WHRS investments on ships using empiric data from different sources comprising expert interviews, focus group meetings, surveys, and case studies. In this sense, we followed the methodology of triangulation by applying and combining several research methods in the study of the same phenomenon. The used qualitative and quantitative studies combined different theories, methods, and empirical data to resolve tentative weaknesses or intrinsic biases related to the research questions by following Altrichter et al. [23] principle of giving a more detailed and balanced picture of the situation.

The empirical work was carried out between 2016 and 2020 in the frame of the EU projects "EnviSuM" and "CSHIPP" in the Baltic Sea Region using statistical data from Eurostat and fuel prices from the Port of Rotterdam in the form of time series of four years complemented the analytical work. The used prices for fuel (MGO) are taken from statistical averages over the last four years. The case study describes a daily operating ferry shuttling between Tallinn and Helsinki. The technical data of the ferry was investigated in desktop research together with expert interviews and observations of maritime positioning systems.

4 Case study and Discussion

Our case study uses a ferry with an engine power of 48 000 kW and a maximal speed of 27 knots so that the travel time between the two ports is about 2 hours between the ports of Tallinn and Helsinki distanced 48 nautical miles and served by several daily plying RoPax. The RoPax ferry operates about 360 days per year and normally makes three roundtrips per day. The daily fuel consumption is about 60 tons of MGO, which yields an annual MGO bunkering volume of 60 tons x 360 days = 21 600 tons.

A WHRS installation on this RoPax ferry would be of type ST-PT, i.e. a combined Steam Turbine-Power Turbine generator units with a maximal electric recovery rate of 8-11% since the main engine has a performance above 25 000 kW. The investment cost (CapEx) of such an ST-PT system is about 9 million € and the annual maintenance costs account for 27 000 €. The lifespan of the ST-PT system is 20 years and the energy-saving rate, in this case is 10%. With an average fuel price of 450 € per ton and a long-term discount rate of 2.5%, we get the following results from capital budgeting calculations:

- NPV_{20y}: 0.3 million €
- Payback Period: ca. 19 years
- IRR 2.8%

The outcome of capital budgeting calculations with the average fuel price of ca. 450 € for MGO in Rotterdam yields a low NPV value of around 300 t€ over 20 years. Taking into account the current MGO price in the first-half year of 2020 that averages around

270 € then the corresponding NPV would be negative (besides, a payback period of about 19 years is too long for a favorable investment). Finally, the IRR ranges close to the risk-free interest rate of about 2.5% for a long-term loan so that the installation of an ST-PT WHRS cannot be recommended. It is remarkable, however, that our calculation yields a relatively long payback period compared to other studies that estimate the payback period for WHRS installations to be between 4 - 7 years [24].

For the calculation of the real-option model in addition to the already known values, the volatility effect of the fuel price is also necessary. Thus, a time series analysis reveals a volatility of 20% over the four years evaluated. By assuming the same volatility for the upcoming years, we get the following results for the Black-Scholes model:

- d1 = -2.80; N (d_1) = 0.0026
- d2 = -3.69; N (d_2) = 0.0001
- Value of the call option C: 0.17 million €

The results of the classical real-option model show that the value of the call option C is only about half the result of the NPV. This outcome is surprising because usually, the value of a real-option call is higher than the NPV since it includes the option of deferring the investment, i.e. to wait until the frame conditions are more favorable instead of an immediate investment. Generally, investment decisions are related to opportunity costs in the case of deferring, thus the WHRS investment should only be realized when the NPV value is higher than the real-option call, which appears in the ferry case. However, in this case, the NPV is low and the value of the call option already takes about half of the NPV so a decision for the WHRS installation should be denied taking into account the long lifespan of the investment together with other uncertainties including the interest rate and the fuel price.

A pragmatic way out is to analyze the result with a fuzzy real-option model that requires an estimation using trapezoidal fuzzy numbers of the present values of expected cash flows together with expected costs of the WHRS [21]. Since in this case the costs of the WHRS are already known in the moment of decision-making, we simplify the model by using a fixed value for the investment costs (i.e. CAPEX). By assuming a range of about 20% for the NPV we come to a trapezoid function with the base points 0.22 and 0.38 million € that range around the value of 0.3 million € for the expected NPV as seen in figure 2:

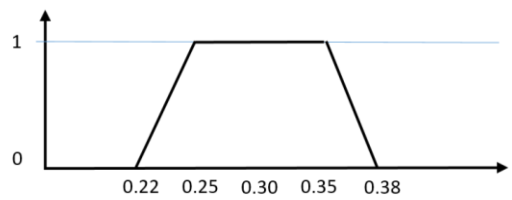

Fig. 2. The Trapezoidal fuzzy function of the ferry (authors' calculation)

By applying the FROA model of Carlsson and Fuller [21], the evaluation of WHRS investment on the ferry between Tallinn and Helsinki results in a trapezoid, which is shaped like the trapeze in figure 2 with an expectation value of -340 € where all base points have negative return values. Similar to previous results, the results of the fuzzy ROA clearly indicates a non-favorable investment decision that leads to negative returns under the assumed circumstances.

Summing up the results of the classical real-options, as well as the fussy real-option analysis, it turns out that the WHRS investment does not make economic sense in the current circumstances. The majority of studies on WHRS highlight the benefit of these installations in shipping, however; most of these studies were made when fuel prices were higher and business environmental situations different. Furthermore, most of these studies did not focus on short-term ferry shuttles but rather on vessels with long-haul voyages like container, bulker, or tanker shipping so that the operational profiles of the studied ships differ fundamentally from our ferry case.

Nevertheless, our approach for financial assessment of WHRS installations showed its potential for the evaluation of maritime investment and the model is easily transferable to other green shipping investments because of its advantage that allows the inclusion of resource-price volatility inclusion in any analysis. Currently, low oil prices foil the installation of energy-saving technology.

5 Conclusion

The implementation of the IMO regulations for sulphur, nitrogen, and CO2 is being realized gradually. Apart from the reduction of ship emissions, energy efficiency is a top priority of the maritime political agenda. This is why to ensure the continuous reductions of CO2 emissions, IMO insists on Energy Efficiency Design Index (EEDI) for ships. A potential technical answer is fuel saving using waste heat recovery systems (WHRS) on ships.

Until now, the financial assessment of WHRS installations on ships are rare and the evaluation of existing models are usually based on capital budgeting concepts, which neglect the volatility of the business environment. The research advocates the application of real options models including fuzzy real-option approaches for the economic assessment of WHRS investments and applies the method in a case of a ferry shuttle between Estonia and Finland.

The results reveal that with the current oil prices the investment in a maritime WHRS installation is not favorable. The research also points out that the use of a real-option model allows the ship owner to take into account and evaluate a deferral option linked to each investment decision. Be it as it may, interesting future studies would be to investigate the outcome of evaluation with other different ship parameters and voyages.

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